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# DIARSENIDES AS SILVER PRECIPITANTS.

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It has been known for a long time that crystals of metallic silver are quickly formed on the surfaces of certain arsenical minerals immersed in a solution of a silver salt and mineralogists have used this knowledge in a qualitative way to detect such minerals as niccolite, smaltite, and löllingite.

As a contribution to the study of silver enrichment Palmer and Bastin[2] have reported the results of quantitative experiments on the reaction that takes place between niccolite and silver sulphate solution. It was learned that coincident with the precipitation of silver the monarsenide, niccolite, is completely dissolved as nickelous sulphate and arsenious acid and that the proportions of the participants in the reaction may be expressed by the equation

$$2NiAs + 5Ag_2SO_4 + 3H_2O = 2NiSO_4 + As_2O_3 + 3H_2SO_4 + 10Ag.$$

One gram of niccolite, therefore, is capable of precipitating 4.02 grams of metallic silver, and this amount of silver deposited from the silver sulphate solution is a direct consequence of the formation of arsenious acid from the arsenic of the simple nickel arsenide.

[1] By permission of the Director of the United States Geological Survey.

[2] Palmer, Chase, and Bastin, E. S., Metallic Minerals as Precipitants of Silver and Gold, ECON. GEOL., Vol. 8, pp. 140–170, 1913.

Similar experiments were subsequently made with maucherite,[3] a newly discovered nickel arsenide containing even a smaller proportion of arsenic than does niccolite. It was found first at Eisleben, Thuringia, and had been recently described by Grünling.[4] Walker[5] independently discovered it among several other minerals occurring in the Canadian cobalt-nickel mining region.

The physical properties ascribed to both the Thuringian and Canadian minerals were closely concordant, but from the chemical analyses that had been made of them two distinctly different empirical formulas were deduced, so that solely on the basis of chemical analyses the existence of two new species of nickel arsenides, both of them lower in arsenic than niccolite, went on record.

From the writer's experiments made afterward on typical specimens of the massive nickel arsenide received from the original Thuringian and Canadian sources it was found that the mineral from both localities dissolves readily in the silver sulphate solution and that its solution products are identical with those obtained from niccolite, namely, nickelous sulphate and arsenious acid. The atomic proportions of the constituents of the dissolved substance obtained from both localities, however, always correspond to the proportions required by the formula $Ni_4As_3$. It is clear, therefore, that the soluble component of the Thuringian specimen is identical with the chief component of the mineral mixture obtained from Canada. Both are representatives of the species whose chemical composition is indicated by the name tetranickeltriarsenide. Thus by determining the products formed in a reaction the chemical proportions of the constituents of a doubtful substance have been directly ascertained and its empirical formula has been established. It was also determined that one gram of tetranickeltriarsenide is capable of precipitating 3.9

[3] Palmer, Chase, Tetranickeltriarsenid und seine Fähigkeit Silber auszufällen, *Zeitsch. für Kryst.*, u. s. w., Vol. LIV., pp. 433–441, 1914. Also, ECON. GEOL., Vol. 9, pp. 664–674.

[4] Grünling, F., "Maucherit, ein neues Nickelmineral," *Centralbl. Mineralogie*, p. 225, April 15, 1913.

[5] Walker, T. L., "Temiskamite, a New Nickel Arsenide from Ontario." *Am. Jour. Sci.*, 4th ser., Vol. 37, pp. 170–172, 1914.

grams of metallic silver and that as a silver precipitant its capacity, like that of niccolite, depends on a simple reaction involving the oxidation of all its arsenic to arsenious acid.

To learn to what extent arsenides in general share with these two lower arsenides, niccolite and maucherite, the power to precipitate silver from silver salt solutions the study of the precipitation capacities of several higher arsenides has been undertaken and the conduct of three diarsenides toward silver sulphate solutions is described in the following pages.

### SMALTITE AND SILVER SULPHATE SOLUTION.

The specimen purporting to come from Buffalo mine, Cobalt, Ontario, was crushed and the steel-gray particles freed as far as possible from gangue. The selected material was ground to a fine powder and analyzed.

*Composition by Gross Analysis.*

Co(Ni) 19.99; Fe 7.97; As 68.78; S 2.02; total 98.76 per cent.

### EXPERIMENT.

The finely powdered mineral (.4025 gram) was digested in about 600 c.c. of a solution containing 3.5 grams of silver sulphate. Action began promptly, metallic silver was deposited, and the solution became pink. After 24 hours the small quantity of dark residue together with an abundant precipitation of metallic silver, was filtered from the pink solution.

From the insoluble portion was obtained 1.5214 grams of metallic silver corresponding to 378 per cent. of the weight of the original material.

From the solution were obtained

| | |
|---|---|
| Co(Ni) | .0729 gram |
| Fe | .0252 gram |
| As | .2560 gram |
| | .3541 gram |

Atomic ratios of the dissolved constituents:

| | | |
|---|---|---|
| Co(Ni) ..... | 18.11 ÷ 59 = .3069 | .4187 |
| Fe ..... | 6.26 ÷ 56 = .1118 | |
| As ..... | 63.60 ÷ 75 = .8480 | |
| | 87.97 | |

and .4187 : .8480 = 1 : 2.02 = Co(Fe, Ni)$As_2$.

Atomic ratios of the constituents of the insoluble portion of the material:

| | Per Cent. | |
|---|---|---|
| Co(Ni) ..... | 1.88 ÷ 59 = .0319 | .0624 |
| Fe ..... | 1.71 ÷ 56 = .0305 | |
| As ..... | 5.18 ÷ 75 = .0690 | |
| S ..... | 2.02 ÷ 32 = .0631 | |
| | 10.79 | |

and .0624 : .0690 : .0631 = 1.0 : 1.1 : 1.01 = Co, Fe, AsS.

These results show that the arsenical material under examination consists essentially of two distinct substances. One is a somewhat ferruginous cobalt diarsenide corresponding to smaltite ($CoAs_2$), soluble in silver sulphate solution. It comprises practically 88 per cent. of the native material. The other substance, insoluble in the silver solution, comprises about 11 per cent. of the original material. The atomic proportions of its constituents correspond to those of a cobalt arsenosulphide, namely, cobaltite (CoAsS).

RATIO OF THE PRECIPITATED SILVER AND THE DISSOLVED COBALT DIARSENIDE.

| Per Cent. | |
|---|---|
| 378 | ÷ 107.9 = 3.5032 |
| 87.97 | ÷ 209.0 = .4209 |

and .4209 : 3.5032 = 1. : 8.32.

.4025 gram material contains .3541 gram smaltite (mol. wt. 209).

According to these results the smaltite contained in the specimen precipitates silver in the proportion of a fraction over 8 atoms of silver to 1 molecule of smaltite. In other words one gram of this cobalt diarsenide can precipitate as much as 4.29 grams of silver. Earlier experiments by the writer have taught

that the capacity of a nickel arsenide to precipitate silver depends wholly on the arsenic of the simple arsenide, the arsenic becoming oxidized smoothly to arsenious acid while the nickel made available in the course of the reaction merely dissolves in association with the sulphate radicle. Similarly the chief constituents of smaltite enter solution as cobaltous sulphate and arsenious acid. Accordingly, cobalt diarsenide, if pure, would be expected to react with silver sulphate solution in the proportions indicated by the equation: $CoAs_2 + 4Ag_2SO_4 + 3H_2O = CoSO_4 + As_2O_3 + 3H_2SO_4 + 8Ag$. That is, one gram of pure cobalt diarsenide has the capacity of precipitating from solution 4.13 grams of metallic silver. That the excess of silver precipitated by the dissolved smaltite (0.16 gram per gram of the diarsenide used in the experiment) is caused by the iron contained in it will become apparent after considering the products obtained in the following experiment, which deals directly with the reaction between löllingite and dilute silver sulphate solution.

LÖLLINGITE AND SILVER SULPHATE SOLUTION.

Löllingite does not react quickly with cold neutral silver sulphate solution. If, however, the solution be slightly acidified with sulphuric acid and gently heated the reaction begins promptly, the mineral dissolves steadily and silver is deposited in abundance. It is well to keep the temperature of the solution below 60° C., thus guarding against the precipitation of an insoluble iron salt which at higher temperatures might be formed by hydrolytic action. After the solution is kept warm for a day it is set aside in a cool place for several hours, and then the products of reaction may be determined.

The mineral from Reichenstein, Silesia, was massive and steel-gray. It was crushed, freed as completely as possible from gangue, and then analyzed.

*Composition by Gross Analysis.*

Fe 27.96; As 68.52; S 1.95; gangue 1.75; total 100.18 per cent.

EXPERIMENT.

The finely powdered mineral (.2722 gram) was digested in about 750 c.c. of a warm solution containing 4.5 grams silver sulphate slightly acidified with sulphuric acid. After 48 hours the well-cooled solution was filtered from the silver deposit and mineral residue. From this was obtained 1.1078 grams silver corresponding to 407 per cent. of the original material. After removal of the silver the solution yielded:

| | | |
|---|---|---|
| Fe | .0663 gram | = 24.35 per cent. |
| As | .1741 gram | = 63.96 per cent. |
| | .2404 gram | = 88.31 per cent. |

Atomic ratio of the dissolved constituents:

| | |
|---|---|
| Fe | 24.35 ÷ 56 = .4350 |
| As | 63.96 ÷ 75 = .8526 |

and .4350 ÷ .8526 = 1 : 1.96 = $FeAs_2$.

Atomic ratios of the insoluble portion of the specimen exclusive of gangue material:

| | Per Cent. |
|---|---|
| Fe | 3.60 ÷ 56 = .0643 |
| As | 4.57 ÷ 75 = .0609 |
| S | 1.95 ÷ 32 = .0609 |
| | 10.12 |

and .0643 : .0609 : .0609 = 1.05 : 1.00 : 1.00 = FeAsS.

These results show that the natural material contains two different substances, one being soluble in the silver sulphate solution and consisting entirely of iron and arsenic in the proportions represented by the empirical formula $FeAs_2$. This iron diarsenide or true löllingite comprises about 88 per cent. of the specimen. The proportions of the constituents of the other substance, comprising about 10 per cent. of the natural material, correspond very closely to the proportions required for arsenopyrite, FeAsS.

RATIO OF THE PRECIPITATED SILVER AND THE DISSOLVED LÖLLINGITE.

.4537 gram material contains .4007 gram löllingite (mol. wt. 206).

| | Per Cent. |
|---|---|
| Ag | $407.0 \div 107.9 = 3.7720$ |
| $FeAs_2$ | $88.3 \div 206.0 = .4286$ |

and $3.7720 : .4286 = 8.8 : 1$.

These results indicate that as a silver precipitant the capacity of the löllingite is measurably greater than that of the smaltite which has already been considered. In effect, for every molecule of this iron diarsenide dissolved 9 instead of 8 atoms of silver can be deposited. From knowledge recently acquired of the silver precipitation capacity of a metallic arsenide whose positive constituent dissolves as a bivalent radicle and from the well-known fact that ferrous sulphate is oxidized by silver sulphate solution to ferric sulphate with concomitant deposition of metallic silver, the full capacity of löllingite as a silver precipitant may be considered as reached by two distinct chemical processes. At first the löllingite is dissolved yielding products proportionally expressed by the equation

$$FeAs_2 + 4Ag_2SO_4 + 3H_2O = FeSO_4 + As_2O_3 + 3H_2SO_4 + 8Ag.$$

Afterward the ferrous sulphate solution on cooling acts reducingly on more silver sulphate forming products in the following proportions:

$$2FeSO_4 + Ag_2SO_4 = Fe_2(SO_4)_3 + 2Ag.$$

By combining these equations representing the two oxidation steps the equation for the limit of action of silver sulphate solution on the constituents of löllingite is obtained. Thus

$$2FeAs_2 + 9Ag_2SO_4 + 6H_2O = Fe_2(SO_4)_3 + 2As_2O_3 + 6H_2SO_4 + 18Ag.$$

Thus one gram of löllingite can cause 4.71 grams of silver to be liberated from solution.

Unless the ferric sulphate resulting from this reaction is removed the limit of reduction by ferrous sulphate is not reached, for it is well known that ferric sulphate solution dissolves metallic silver forming ferrous sulphate and silver sulphate as follows:

$$Fe_2(SO_4)_3 + 2Ag = 2FeSO_4 + Ag_2SO_4.$$

Stokes[6] has pointed out this reversal and has shown experimentally that heat increases the solubility of metallic silver in ferric sulphate solution, and more recently Cooke[7] has given the relations of ferrous, ferric and silver sulphates in solutions of different concentrations. In experiments on the silver precipitation capacity of an arsenical mineral which supplies an iron salt to the solution from which silver is precipitated precaution should be taken against the solution of silver by reversal of the reaction to the reaction given by Stokes.

In the experiments on the silver precipitation capacities of these iron arsenides the mineral was digested in a warm solution containing a large excess of silver sulphate. After complete dissolution of the mineral, warm concentrated silver sulphate solution was added to reinforce the solution that had been weakened by loss of silver. During the cooling of the solution product a new deposit of metallic silver separated in fine crystals. The solution was not filtered until several hours after it had become cold. All the silver that had been precipitated was then separated from the solution and determined.

### SUMMARY FOR LÖLLINGITE AND SMALTITE.

From the experiment with löllingite it is learned that its iron is in the ferrous state and is therefore bivalent, so that in any graphic formula or other representation of the constitution of the löllingite molecule the bivalent nature of its iron should be considered. From the results of experiments made with the two diarsenides, smaltite and löllingite, it may be taken that one gram of pure smaltite ($CoAs_2$) can precipitate from solution 4.13 grams of metallic silver, whereas one gram of the löllingite ($FeAs_2$) under favorable conditions can precipitate as much as 4.71 grams of silver. Were it not for the energy resident in the bivalent iron of the löllingite, which energy is lacking in the

[6] Stokes, H. N., "Experiments on Solution of Copper, Silver and Gold," ECON. GEOL., Vol. I., pp. 644–650, 1906.

[7] Cooke, H. C., "Secondary Enrichment of Silver Ores," *Jour. Geology*, Vol. XXI., pp. 1–28, 1913.

metallic radicles of the arsenides of cobalt and nickel thus far studied, one gram of löllingite would be incapable of precipitating more than 4.18 grams metallic silver.

SAFFLORITE AND SILVER SULPHATE SOLUTION.

Of the various minerals that have been studied with respect to their conduct with silver sulphate solution, a massive arsenical mineral purporting to have come from Grafton, New Hampshire, is worthy of consideration. Its composition by gross analysis was found to be

Cobalt 13.75; iron 13.85; arsenic 71.12; sulphur 0.76; total 99.48 per cent.

From the percentage composition of its constituents the specimen appears to be essentially a diarsenide containing iron and cobalt in nearly equal amounts. Its specific gravity is 7.08. It may, therefore, be taken to be safflorite and not smaltite, whose specific gravity ranges about 6.5. The higher specific gravity of this mineral is the criterion by which McCay[8] established the position of massive safflorite among diarsenides.

The finely powdered mineral (.2923 gram) was digested 24 hours in a 500 c.c. heated and slightly acid solution containing 3.75 grams of silver sulphate. Action began promptly, the solution became pink and bright metallic silver was precipitated. The pink solution was then cooled and after several hours it was filtered from the dark mineral residue mixed with the copious silver deposit. From this residue 1.2193 grams of silver, corresponding to 417.2 per cent. of the weight of the specimen, were obtained.

From the solution were obtained:

| | | |
|---|---|---|
| Co | .0401 gram | = 13.72 per cent. |
| Fe | .0368 gram | = 12.62 per cent. |
| As | .2019 gram | = 69.10 per cent. |
| | | 95.44 per cent. |

Atomic ratios of the dissolved constituents:

[8] McCay, Leroy W., "Massive Safflorite," *Am. Jour. Sci.*, 3d ser., Vol. 29, pp. 369–374, 1885.

| | Per Cent. | |
|---|---|---|
| Co | 13.72 ÷ 59 = 0.2325 | 0.4578 |
| Fe | 12.62 ÷ 56 = 0.2253 | |
| As | 69.10 ÷ 75 = 0.9213 | |

and .4578 : .9213 = 1 : 2.01 = Co(Fe)$As_2$.

These results show that the true cobalt-iron diarsenide comprises about 95 per cent. of the natural material and that the empirical formula of the soluble substance may be written $CoFeAs_4$.

*Atomic Ratios of the Portion Not Attacked by the Silver Sulphate Solution.*

| | Per Cent. |
|---|---|
| Fe | 1.50 ÷ 56 = .0264 |
| As | 2.02 ÷ 75 = .0269 |
| S | .76 ÷ 32 = .0264 |

and .0264 : .0269 : .0264 = 1.00 : 1.02 : 1.00 = FeAsS.

These ratios correspond to the atomic ratios appertaining to arsenopyrite, FeAsS.

*Ratio of the Precipitated Silver and the Dissolved Safflorite, $Co\frac{1}{2}$, $Fe\frac{1}{2}As_2$ (mol. wt. = 207.5).*

| | Per Cent. |
|---|---|
| Ag | 417.20 ÷ 107.9 = 3.8665 |
| $Co\frac{1}{2}Fe\frac{1}{2}As_2$ | 95.44 ÷ 207.5 = .4599 |

and .4599 : 3.8665 = 1 : 8.41.

One conventional molecular weight of this safflorite (207.5), therefore, precipitates an amount of silver equal to 8.41 times the atomic weight of silver. In other words one gram of the true safflorite in the specimen can precipitate 4.37 grams of silver. By applying to this soluble complex diarsenide our knowledge of the silver precipitation capacity of nickel and cobalt diarsenides in general, which knowledge has been gained by the study of niccolite (NiAs), maucherite ($Ni_4As_3$), and smaltite ($CoAs_2$) with dilute silver sulphate solution, it is clear that if the dissolved mineral were simply a cobalt diarsenide ($CoAs_2$) not more than 400 per cent. of its weight in silver could have been precipitated. On the other hand, if it were the simple ferrous diarsenide, löllingite ($FeAs_2$), then 440 per cent. of its weight in silver would be

looked for. From the observed capacity of this cobalt iron diarsenide to precipitate 417.2 per cent. of its weight in silver the persistence of the bivalent nature of iron in the complex substance, safflorite, is evident.

In microscopic studies of the silver ores of Cobalt, Ontario, (accompanying paper) by Edson S. Bastin, native silver has been observed, not only as a replacement of nickel and cobalt arsenides, but also as a replacement of ferruginous calcite at some distance from the arsenides. This replacement may be attributed to neutralization of acidic ferric solutions by calcite. A ferric salt thus neutralized suffers hydrolysis and the potency of the solution as a silver solvent is correspondingly weakened. Calcite accompanied by ferrous carbonate is even more effective in causing the precipitation of silver, for the iron of the ferrous carbonate enters solution as ferrous sulphate and ferrous sulphate is distinctively a precipitant of free silver. Moreover, in contact with ferric salt solutions, these carbonates are themselves dissolved and thus a place is prepared to receive metallic silver.

From the chemical observations thus far made of the manner in which silver is precipitated by arsenides it may be accepted that if silver salt solutions free from iron salts come in contact with a pure nickel or cobalt arsenide as much silver as possible is deposited within the space abandoned by the arsenide, since the dissolved cobalt and nickel salts resulting from the reaction are not solvents of silver. On the other hand, if the replaced mineral be löllingite, or some other arsenide containing replaceable iron, only a part of the silver may be precipitated within the space occupied by the dissolved arsenide. The remainder of the silver is kept in solution in equilibrium with iron salts formed by reaction with the arsenical iron mineral and may be transported to distant places and there precipitated under conditions favorable for the deposition of metallic silver.

### CONDUCT OF DIARSENIDES, DISULPHIDES AND ARSENOSULPHIDES WITH SILVER SULPHATE SOLUTION.

From quantitative experiments made with the diarsenides smaltite ($CoAs_2$), löllingite ($FeAs_2$), and safflorite ($CoAs_2FeAs_2$)

and with the lower arsenides maucherite ($Ni_4As_3$) and niccolite (NiAs) it appears that silver sulphate solution is an efficient solvent of simple arsenides, for the arsenic of all these simple arsenides is readily oxidized to arsenious acid.

Similar experiments made with well-crystallized specimens of the disulphides pyrite ($FeS_2$), marcasite ($FeS_2$) and hauerite ($MnS_2$) have shown that these disulphides are not attacked by silver sulphate solution and cause no precipitation of metallic silver. In all of these minerals the negative disulphide group ($S_2$) strongly resists oxidation by silver sulphate solution.

Another series of experiments of the same kind made with minerals classed among arsenosulphides, namely, arsenopyrite (FaAsS), cobaltite (CoAsS) and ullmanite (NiSbS), has shown that arsenosulphides do not react with silver sulphate solution. Pure minerals were chosen because in the dissolution of simple arsenides by oxidation with silver sulphate solution residues containing arsenic, sulphur and metal in atomic proportions suggesting residual arsenosulphides were often found.

Just as the disulphide group ($S_2$) in pyrite, marcasite and hauerite resists oxidation so also does the arsenosulphide group (AsS) in arsenopyrite and cobaltite. It appears, therefore, that in the molecules of arsenosulphides sulphur and arsenic functionate together atomically and that in arsenosulphides sulphur is a protector of arsenic against oxidation by silver salt solutions.

From these experiments it may be taken that in regions abounding in native silver associated with arsenides, arsenosulphides and disulphides the source of the silver is to be attributed, not to the action of disulphides nor to the action of arsenosulphides, but rather to the action of simple arsenides on silver salt solutions.

# SIGNIFICANT MINERALOGICAL RELATIONS IN SILVER ORES OF COBALT, ONTARIO.*

EDSON S. BASTIN.

## INTRODUCTION.

Since the spectacular discovery of silver at Cobalt in 1903 the ores of the Cobalt district have been a favorite object of study by American geologists, both because of the remarkable richness of the ores and because they form the only important Amercian example of that type of deposit in which native silver is abundantly associated with nickel and cobalt minerals. The writer has never visited the Cobalt district but his microscopic studies of the ores of that region reveal certain significant mineral relations not hitherto described, and it is believed that a report of these relations will be useful to students of ore deposits. Coordinate with these microscopic studies, a series of chemical experiments on the conduct of a number of the ore minerals with silver sulphate solutions has been carried on by Chase Palmer. Some of the results of his experiments are separately reported by him[1] and in the present paper consideration will be given to their bearing on the genesis of the ores.

Some of the most instructive specimens used for microscopic study were collected by the late S. F. Emmons, and by him deposited in the Geological Survey's collection. Other specimens were generously supplied by F. L. Ransome and F. L. Hess.

## PUBLISHED OPINIONS OF GENESIS.

To make clear the principal problems of genesis which the ores of the Cobalt district present, it is desirable to summarize briefly

* Published with the permission of the Director of the United States Geological Survey.

[1] Palmer, Chase, "Diarsenides as Silver Precipitants" (companion article, this journal).

the opinions that have been published by several geologists familiar with the region.

*Relations Between Ore Deposition and Diabase Intrusion.*—C. R. Van Hise,[2] W. G. Miller,[3] R. E. Hore,[4] and A. E. Barlow[5] have all expressed the belief that the deposition of the ores was genetically connected with the intrusion of the pre-Cambrian diabases of the region. As to whether the solutions responsible for the primary mineralization were a product of magmatic differentiation within the diabase magma and thus strictly magmatic, or were meteoric waters invigorated and mineralized through contact with the hot diabase, Van Hise specifically says he does not know. Miller shows similar caution, though apparently favoring a magmatic derivation; Hore and Barlow believe the solutions were magmatic.

*Dual Mineralization.*—All of the writers that have been cited as well as S. F. Emmons[6] and Messrs. W. Campbell and C. W. Knight,[7] have recognized that the native silver was in the main a later deposition than the cobalt and nickel arsenides, although there have been some differences of opinion as to the relative ages of certain of the other ore minerals. Miller in his latest report[8] gives the following order of deposition from youngest to oldest in descending order.

III. Decomposition products, *e. g.*, erythrite, annabergite, and asbolite.

II. Rich silver ores and calcite.

[2] Van Hise, C. R., "The Ore Deposits of the Cobalt District, Ontario," *Canadian Min. Inst. Jour.*, Vol. 10, 1907, pp. 45–61.

[3] Miller, W. G., "The Cobalt-nickel Arsenides and Silver Deposits of Temiskaming," Rept. Ontario Bur. Mines, Vol. 19, pt. 2, 1913.

[4] Hore, R. E., "Origin of Cobalt-silver Ores of Northern Ontario," *Canadian Min. Inst. Jour.*, Vol. 11, 1908, pp. 275–286.

[5] Barlow, A. E., "The Origin of the Silver of James Township, Montreal River Mining District," *Canadian Min. Inst. Jour.*, Vol. 11, 1908, pp. 256–272.

[6] Emmons, S. F., Cobalt District, Ontario, in "Types of Ore Deposits," published by Min. and Sci. Press, 1911, pp. 140–156.

[7] Campbell, W., and Knight, C. W., "A Microscopic Examination of the Cobalt-nickel Arsenides and Silver Deposits of Temiskaming," ECON. GEOL., Vol. 1, pp. 767–776, 1905.

[8] *Ibid.*, p. 10.

I. Smaltite, niccolite, and dolomite.

Miller says further:

"After the minerals of Group I. were deposited the veins were subjected to a slight movement. In the cracks thus formed the minerals of Group II. were deposited."

*Source of the Silver-Bearing Solutions.*—The main divergence of opinion concerning the genesis of the ores has been in regard to the source of the native silver which was deposited within the nickel and cobalt arsenide ore after the latter had been fractured. Barlow and Hore have regarded the silver-bearing solutions as coming at a later period from the same magmatic source as the solutions which deposited the cobalt and nickel arsenides. The time interval between the two mineralizations Hore[9] believes was short. Miller[10] regards most of the silver as a primary deposition in the sense that it was not derived from the breaking down of earlier silver-bearing ore minerals. The argentiferous solutions therefore originated outside the nickel-cobalt ore bodies. Presumably he regards them as of magmatic origin though he is not specific on this point. Relatively minor amounts of argentite, proustite, and native silver occurring in vugs and open spaces below the productive zone, he considers as probably the result of downward enrichment. While unwilling to assert that *all* of the native silver of the Cobalt ores is the result of downward enrichment, Van Hise believes that the extremely rich superficial deposits are the result of downward enrichment ("a secondary concentration under surface conditions"), and that the same process has at least made important contributions to the silver content of the deeper ores. S. F. Emmons considers that all of the rich silver ores are a product of downward enrichment. He says:[11]

"I could find no evidence that the silver had been introduced from below by later accession of metal-bearing solutions, . . . and I am inclined to believe that the second period of fracturing has served simply to furnish channels for descending silver solutions."

[9] *Ibid.*, p. 281.
[10] *Ibid.*, pp. 12 and 13.
[11] *Ibid.*, p. 151.

*Agents of Silver Precipitation.*—Van Hise in 1907[12] suggested that the cobalt and nickel sulphides and arsenides were the agents which had precipitated the silver of those veins. In 1913 Palmer and Bastin[13] not only observed that the simple arsenide niccolite precipitates silver rapidly from silver salt solutions but they also determined quantitatively its capacity as a precipitant of free silver. They observed, moreover, that the sulphides millerite and pyrite do not react readily with silver solutions. Afterwards Palmer[14] found that arsenosulphides of nickel, cobalt, and iron, like the bisulphides of iron, resist the action of silver salt solutions and he was therefore led to conclude that where metallic silver is associated with the arsenical minerals the precipitation of the silver should be attributed to the action of simple arsenides rather than of arsenosulphides on silver salt solutions. Miller[15] quotes some of these experimental results and apparently regards them as applicable in solving the problem of the genesis of these deposits.

*Composition of the Silver-Bearing Solutions.*—Miller has suggested that, in view of the abundance of calcium carbonate in the silver veins, the silver may have been carried mainly in bicarbonate solution. Palmer and Bastin,[16] while showing that cobalt and nickel arsenides do precipitate metallic silver from dilute solutions of silver sulphate, have not committed themselves as to the actual form in which the silver was transported in the natural occurrences at Cobalt.

[12] *Ibid.*, pp. 46 and 47. "After the main deposition of the cobalt minerals, there were movements which resulted in secondary fracturing of the veins. These openings permitted the entrance of silver-bearing solutions, and the contact of these solutions with the cobalt minerals resulted in the precipitation of the silver. It is a well-known fact that if silver solutions be placed in contact with cobalt and nickel sulphides and arsenides under ordinary conditions these minerals will precipitate the silver."

[13] Palmer, Chase, and Bastin, E. S., "Metallic Minerals as Precipitants of Silver and Gold," ECON. GEOL., Vol. 8, pp. 140–170, 1913.

[14] Palmer, Chase, "Tetranickeltriarsenide, its Capacity as Silver Precipitant," ECON. GEOL., Vol. 9, pp. 664–674, 1914.

[15] *Ibid.*, p. 12.

[16] *Ibid.*, p. 166.

### ORE MINERALS.

The minerals recognized in the specimens, the study of which forms the basis of this communication, were smaltite, niccolite, breithauptite, chalcopyrite, calcite (mainly ferruginous), native silver, and polybasite(?). The chalcopyrite was not noted on any polished surface, so that its age relations to the other minerals were not positively determined. Under the hand lens it appears to be contemporaneously intergrown with smaltite.

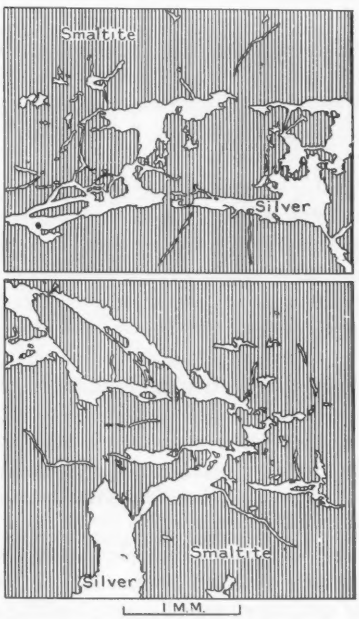


FIG. 3. Replacement veinlets and lenses of native silver traversing smaltite. Camera lucida drawing from polished surface of ore from Cobalt district, exact locality uncertain.

The mutual relation of smaltite, niccolite, breithauptite, and ferruginous calcite will first be considered and later the relations of the silver and polybasite(?) to the other ore minerals.

*Mutual Relations of Smaltite, Niccolite, Breithauptite, and Calcite.*—One of the most characteristic textural features of the Cobalt ores is the tendency of these minerals, particularly of the metallic minerals, to assume concentric arrangements. In some specimens, as shown in Plate VIII., *C*, two minerals form a large number of alternating bands. Miller[17] has published an illustration of an ore specimen in which there are at least twenty-five well-defined bands of smaltite alternating with bands of calcite. In most ore specimens the relations are simpler. In some specimens, as shown in the lower left corner of Fig. 4 and in Plate IX., *B*, single shells of smaltite surround cores of calcite or shells of smaltite may inclose or partially inclose cores of breithauptite, niccolite, or both. Viewed with the unaided eye, the concentric intergrowths commonly present the "cluster-like" form shown in Fig. 3.

In the past geologists have usually explained phenomena of this sort as due to simple sequential deposition of minerals from solution. While such an hypothesis may seem adequate to explain the simpler forms, the weakness of the explanation for specimens showing many alterations of two minerals lies in the difficulty of conceiving adequate causes for frequent and regular variations in the composition of the solutions or for pulsating variations of temperature or pressure during crystallization. The most plausible explanation, and one recently adopted by a number of students of ore deposits as a tentative explanation of such phenomena, is the rhythmic precipitation hypothesis developed by Liesegang.[18] Such multiple banding certainly merits description wherever encountered.

In the Cobalt ores showing multiple banding, smaltite, niccolite, and calcite were observed interbanded. In other specimens single bands of smaltite surround cores of calcite, of niccolite or of breithauptite. The writer believes that these relationships indicate the essential contemporaneity of niccolite, breithauptite,

[17] *Ibid.*, p. 15, Fig. 11.

[18] Liesegang, R. E., "Geologische Diffusionen," 1913. Also Morse and Pierce, "Diffusion und Übersättigung in Gelatine," *Zeitschr. phys. Chem.*, Vol. 45, 1903, pp. 589–607.

smaltite, and at least some of the calcite. Smaltite, and more rarely niccolite, is traversed in some specimens by numerous minute veinlets of calcite, many of which are offshoots from the general calcite matrix. A number of these are shown in Plate VIII., *A*, and one is shown at *V* in Plate IX., *C*. These are interpreted as only slightly later than the smaltite and as the result of fracturing during the late stages of the primary mineralization. Locally as in the specimen shown in Plate IX., *C*, they have been partially replaced by silver.

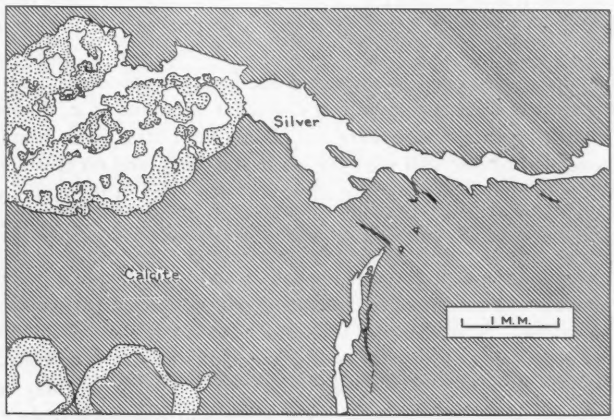


FIG. 4. Replacement veinlet of silver traversing ferruginous calcite, continuous with silver that is believed to be a replacement of cobalt and nickel minerals (dotted: smaltite and some breithauptite and niccolite, undifferentiated in the drawing). Camera lucida drawing of ore from Crown Reserve mine.

*Relations of Native Silver to the Other Ore Minerals.*—One characteristic feature of the rich silver ores is that much of the silver occurs as small veinlets in the ferruginous calcite gangue. These veinlets commonly form parts of a vein system which, as shown in Plate VII., *A*, exhibits a certain amount of regularity in its larger features. There is, for example, a tendency for many of the veinlets of silver to parallel the trend of the vein as a whole.

As particularly well shown in Plate VIII., *B*, many pursue nearly rectilinear courses until a point is reached where they abruptly shift to another rectilinear course. Such relations seem to indicate that the veins are related to fractures developed in the calcite mainly along calcite cleavages. Under higher magnification it is seen, as shown in Plate IX., *A*, that in detail the boundaries of the veinlets are very irregular and that opposite boundaries do not match.

While the general vein-like forms assumed by the silver indicate that it is later than the calcite, the irregularities of these veinlets when viewed in detail show that a part at least of the silver is not a simple deposit in open fractures. A small part of the silver may have filled open fractures but the fact that opposite sides of the veinlets are as a rule entirely dissimilar in outline (*i. e.*, do not "match"), even where there has plainly been little or no lateral movement of one wall with respect to the other, and no crushing of the calcite, shows that the silver was deposited in the main by metasomatic replacement of the calcite starting from minute cracks, many of which followed the cleavage. According to this conception the deposition of the calcite and the nickel and cobalt minerals was succeeded by fracturing which affected particularly the calcite. Silver-bearing solutions penetrating these fractures dissolved calcite from the walls and simultaneously deposited silver in its place. The silver veinlets of Plate IX., *A*, may be regarded as typical of replacement veinlets in which the replacement has affected unequally opposite walls of a fracture. The silver veinlet shown in Plate X., Fig. 6, of Campbell and Knight's article[19] and possibly the vein of argentite shown in their Fig. 2, would also be interpreted by the present writer as replacement veinlets.

The relations between native silver and the minerals smaltite, niccolite, and breithauptite, are more complex. A small specimen from the Cobalt district, exact locality uncertain, shows when polished a network of irregular silver veinlets traversing smaltite in the fashion shown in Fig. 3. The veinlets and irregular masses

[19] *Ibid.*, opp. p. 772.

of silver in this specimen are interpreted by the writer as replacement veinlets. Their irregularity as compared with the silver veinlets in calcite shown in Plate VIII., *B*, is attributed to more irregular fracturing of smaltite than of calcite prior to replacement, an irregularity consequent upon its much less perfect cleavage.

Attention has already been directed to the common occurrence of the primary Cobalt ore minerals in cluster-like forms usually composed of two or more of these minerals in concentric arrangement, one of the commonest arrangements consisting of cores of niccolite or breithauptite (more rarely, both) surrounded by a border of smaltite. In a number of specimens all gradations are traceable in the cluster-like aggregates from those showing cores of pure niccolite or breithauptite inclosed by smaltite, through others whose cores are part native silver (occasionally with some polybasite(?)) and part breithauptite or niccolite, as shown in Plate IX., *B*, and Fig. 4, into others whose cores are practically entirely native silver, as shown in Plate VII., *B*. That such occurrences of native silver within the cluster-like aggregates of nickel and cobalt minerals are replacements of niccolite or breithauptite is further indicated by their entire continuity in places with the silver veinlets traversing calcite as is shown in Fig. 4.

Native silver was also observed in a third mode of occurrence, and in this occurrence also may be associated with some polybasite(?). The specimen from the Kerr Lake mine, in which this mode of occurrence was noted, exhibits a veinlet ¾ inches in width consisting of ⅛ to ¼ inches of calcite next the walls, followed by smaltite which incloses, in the central part of the vein, irregular areas mainly niccolite but in small part silver, polybasite(?), and calcite. A little breithauptite is in places intergrown irregularly with the niccolite. Where niccolite alone occurs with the smaltite the two minerals are associated in a fashion indicative of essential contemporaneity. Both minerals, but particularly the smaltite, have been considerably fractured. Some of the smaller areas or "nests" of other minerals within the smal-

tite have the form shown in Plates VIII., *D*, IX., *C* and IX., *D*, the smaltite that surrounds them showing crystal outlines. Certain of the "nests," as shown in Plate VIII., *D*, are mainly niccolite; others, as shown in Plate IX., *C*, consist of rounded areas of niccolite in a matrix that may be wholly silver or an irregular aggregate of silver and polybasite(?);[20] still others are almost wholly silver as shown in Plate IX., *D*, or the silver-polybasite(?) aggregate. Where polybasite(?) and silver occur in the "nests" they are irregularly intergrown, the intergrowth occupying precisely the position that silver alone does in other "nests."

These "nests" on casual inspection might be looked upon as contemporaneous intergrowths of niccolite, in differing proportions, with silver, polybasite(?), or both, but the fact that some nests are wholly niccolite while others are wholly native silver or silver and polybasite(?) suggests that all were originally niccolite. Furthermore, the rounded outlines of the niccolite inclosed by silver or by the silver-polybasite(?)-calcite aggregates favors their interpretation as remnants left in a process of replacement of niccolite by silver or by the silver-polybasite(?) aggregate.

## SUMMARY OF MICROSCOPIC STUDIES.

Microscopic evidence has been presented to show that in a collection, probably fairly representative of the rich silver ores of the Cobalt district, smaltite, niccolite, breithauptite, and ferruginous calcite form the earliest generation of minerals. These minerals were deposited essentially contemporaneously, and frequently show a concentric arrangement suggestive of the diffusion phenomena described by Liesegang.

Evidence is further presented to show that all of the above-mentioned minerals of the first generation have been replaced by native silver and to a minor degree by polybasite(?). All the

[20] Polished surfaces under microscope, smooth and light gray; soft, brittle, with black streak; unaffected by concentrated $HNO_3$, HCl, or by $FeCl_3$ or $H_2O_2$; tarnishes brown slowly with $AgNO_3$, and rapidly with $HgCl_2$. Blackens with KOH. The mineral is in too small amounts to be isolated for testing but from its associations, physical properties, and behavior with reagents, is believed to be a sulpho-salt of silver, probably polybasite.

silver and polybasite of the specimens studied appears to have been deposited by these replacement processes, possibly accompanied locally by a minor amount of deposition in small open fractures.

TABLE I.

NATURAL ASSOCIATION OF IRON, NICKEL, AND COBALT WITH SULPHUR, ARSENIC AND ANTIMONY, AND SOME ARTIFICIAL ANALOGUES.

| | | Not decomposed | | | Decomposed | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Compounds with sulphur and arsenic | Iron | FeS, artificial troilite | $FeS_2$, *pyrite marcasite* | FeAsS, *arsenopyrite* | $Fe_4As_2$, artificial | | | FeAs, artificial | $FeAs_2$, **löllingite** | |
| | Nickel | NiS, *millerite* | $NiS_2$, artificial | NiAsS, gersdorffite | $Ni_4As_2$, artificial | $Ni_2As_2$, artificial | $Ni_4As_2$, **maucherite** | NiAs, **Niccolite** | $NiAs_2$, Chloanthite and Rammelsbergite | |
| | Cobalt | CoS, artificial | $CoS_2$, artificial | CoAsS, *cobaltite* | | $Co_2As_2$, artificial | | CoAs, artificial | $CoAs_2$, **smaltite** and **safflorite** | $CoAs_3$, skutterudite |
| Compounds or alloys with sulphur and antimony | Iron and cobalt | Alloys with antimony | | | | | | | | |
| | Nickel | | | NiSbS, *ullmannite* | | | | NiSb, **Breithauptite** | | |

Compounds or alloys in italics are not decomposed by solutions of silver sulphate; those in bold-face type are decomposed. Behavior of others is undetermined, but may be inferred from their position in the table.

*Chemical Interpretation.*—In the following pages it will be the writer's purpose to show that the replacements that have been described in the ores of Cobalt can be adequately explained on the premise that they were accomplished by argentiferous sulphate solutions, probably acidic and iron-bearing. Solutions of this character would be likely to be formed by the combined action of air and meteoric waters on the lodes and the changes they wrought would be comprised under the term downward enrichment.

EXPLANATION OF PLATE VII.

FIG. A. Polished surface of rich silver ore (about 5,000 oz. to the ton) from 350-foot level of Kerr Lake mine, Cobalt. Cluster-like masses of primary smaltite and breithauptite (light gray) are embedded in primary calcite (dark gray). The calcite is traversed by a network of small replacement veinlets of native silver (white) and there has also been some replacement of the metallic minerals by silver.

FIG. B. Occurrence of native silver (Ag) as replacement veinlet in ferruginous calcite, as replacement of calcite along its contact with smaltite (Sm), and as a replacement of cores of niccolite, only small remnants of which (N) remain. Magnified 30 diameters. Kerr Lake mine.

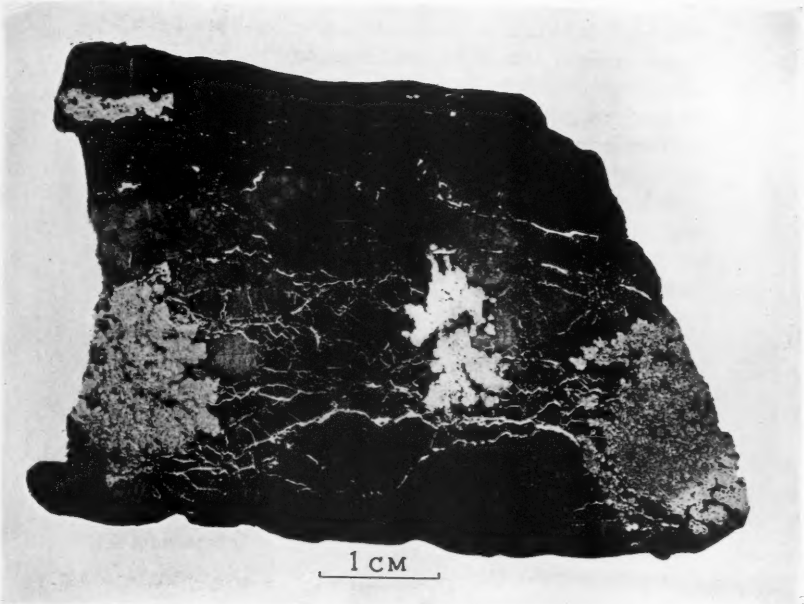


FIG. A.

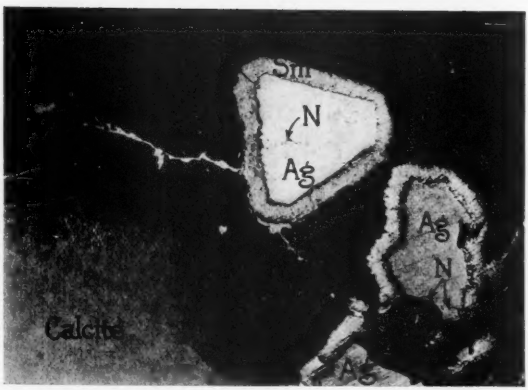


FIG. B.

In Table I. are listed most of the known natural or artificial compounds or alloys of iron, nickel, and cobalt with sulphur, arsenic, and antimony. Of the natural minerals of this table, millerite, pyrite, arsenopyrite, cobaltite, maucherite, niccolite, breithauptite, chloanthite, and smaltite have been identified by various observers in the ores of Cobalt, Ontario. Of the minerals in the table those in italics have been found by Palmer to be ineffective, and those in bold-face type effective, in precipitating metallic silver from solutions of silver sulphate or silver nitrate. The behavior of the others toward silver solutions may be inferred with a fair degree of probability from their position in the table with reference to those whose action is known.

The experiments with all these minerals except breithauptite have been carried out quantitatively. The pure breithauptite available was insufficient for quantitative study but qualitative tests show that it is an effective silver precipitant. From the quantitative studies the following reactions have been established by Palmer.[21]

(1) Maucherite,

$$2Ni_4As_3 + 17Ag_2SO_4 + 9H_2O = 8NiSO_4 + 3As_2O_3 + 9H_2SO_4 + 34Ag.$$

(2) Niccolite,

$$2NiAs + 5Ag_2SO_4 + 3H_2O = 2NiSO_4 + As_2O_3 + 3H_2SO_4 + 10Ag.$$

(3) Smaltite,

$$CoAs_2 + 4Ag_2SO_4 + 3H_2O = CoSO_4 + As_2O_3 + 3H_2SO_4 + 8Ag.$$

(4) Löllingite,

(*a*) $$FeAs_2 + 4Ag_2SO_4 + 3H_2O = FeSO_4 + As_2O_3 + 3H_2SO_4 + 8Ag.$$

(*b*) $$2FeSO_4 + Ag_2SO_4 = Fe_2(SO_4)_3 + 2Ag.$$

[21] For maucherite, see ECON. GEOL., Vol. 9, pp. 664–674, 1914. For niccolite, see ECON. GEOL., Vol. 8, pp. 140–170, 1913. For smaltite, löllingite and safflorite, see this journal, pp. 209 to 216.

## EXPLANATION OF PLATE VIII.

FIG. A. Irregular association of smaltite and ferruginous calcite. Dark veinlets in smaltite are calcite continuous with that of the matrix and probably only slightly later than the smaltite. Kerr Lake mine below 350-foot level, No. 3 shaft.

FIG. B. Enlarged view of part of the polished surface shown in Plate VII A, showing replacement veinlets of native silver in ferruginous calcite. The replacement has in several places followed cleavage planes in the calcite.

FIG. C. Microphotograph of polished surface of ore from Pem-Canadian mine, showing concentric banding of smaltite (Sm) and niccolite (N). In places smaltite, elsewhere niccolite, forms the outer band. Matrix, black in the photograph, is calcite, slightly ferruginous.

FIG. D. "Nest" of niccolite (N) with some native silver (Ag), inclosed by smaltite (Sm). Ore from depth of 250 feet in Kerr Lake mine.

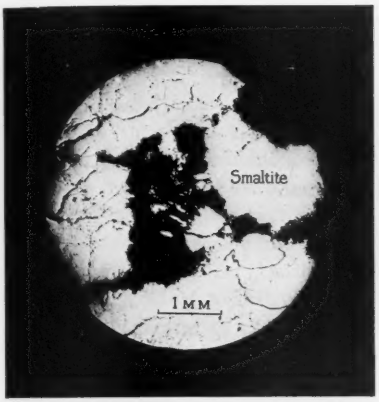


FIG. A.

FIG. B.

FIG. C.

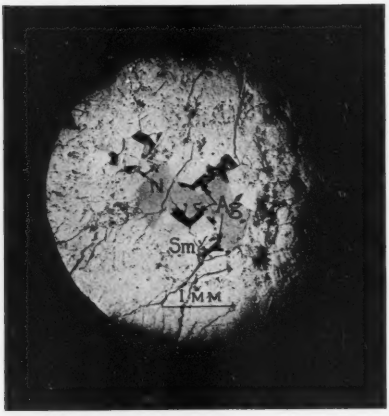


FIG. D.

Combining

$$(a+b)\ 2FeAs_2 + 9Ag_2SO_4 + 6H_2O = Fe_2(SO_4)_3 + 2As_2O_3 + 6H_2SO_4 + 9Ag.$$

(5) Safflorite used experimentally contained $CoAs_2$ and $FeAs_2$ in equivalent amounts. Its behavior would be expressed by a combination of equations (3) and (4).

Reactions of the order shown by these equations offer a rational chemical explanation of the processes involved in the replacements of smaltite, niccolite, and breithauptite by native silver in the Cobalt ores. Furthermore, the microscopic evidence that in mixtures of smaltite and niccolite, niccolite is replaced by silver to a greater extent than smaltite, tallies with experimental evidence that niccolite is attacked more rapidly by silver sulphate solution than is smaltite. At the writer's suggestion, Dr. Palmer treated a powdered mixture containing .1430 gram true niccolite and .1552 gram true smaltite for 30 minutes with silver sulphate solution. At the end of that period approximately 72 per cent. of the niccolite had dissolved but only 9 per cent. of the smaltite.[22]

[22] The powdered mixture (.4005 gram) containing .1430 gram true niccolite and .1552 gram true smaltite was digested for thirty minutes in a silver sulphate solution. The remaining constituents of the mixed minerals were chiefly cobaltite and other substances, all of which are resistant to the action of silver sulphate solution. After the excess of silver was removed the solution was found to contain

| | |
|---|---|
| Nickel | .0444 gram |
| Cobalt | .0034 gram |
| Arsenic | .0660 gram |

.1430 gram of the true niccolite used contained .0629 gram nickel, but no cobalt. The solution, therefore, contains 70.6 per cent. of the nickel of the niccolite and this nickel corresponds to .0567 gram arsenic dissolved with the nickel from the niccolite. The ratio of the remainder of the dissolved arsenic (.0093) and the cobalt (.0034 gram) likewise in the solution is

| | |
|---|---|
| Arsenic | $.0093 \times 1000 \div 75 = .124$, |
| Cobalt | $.0034 \times 1000 \div 75 = .058$, |

and $.058 : .124 = 1 : 2.1$.

Inasmuch as the niccolite is wholly free from cobalt it is permissible to

## EXPLANATION OF PLATE IX.

FIG. A. Enlarged view of part of the polished surface shown in Plate VII, A, showing minor irregularities of the silver veinlets in calcite. Opposite walls of the silver veinlets do not match.

FIG. B. Cores of native silver (dotted) in smaltite (Sm). The silver is a replacement of niccolite, remnants of which (N) remain within the silver. Black to dark-gray areas are ferruginous calcite. Magnified 30 diameters. Ore from Kerr Lake mine.

FIG. C. "Nest" of niccolite (N) and silver (Ag) inclosed by smaltite (Sm). The silver is probably a replacement of niccolite (N). Note the somewhat rounded outlines of the niccolite remnants.

FIG. D. "Nest" of silver (Ag) in smaltite. There is a single small remnant of niccolite (N). Small black patches in the silver and in the veinlet (V) are primary calcite.

FIG. A.

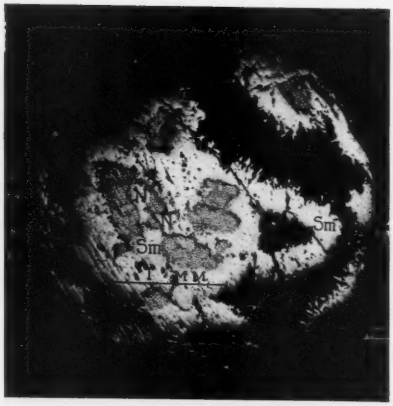


FIG. B.

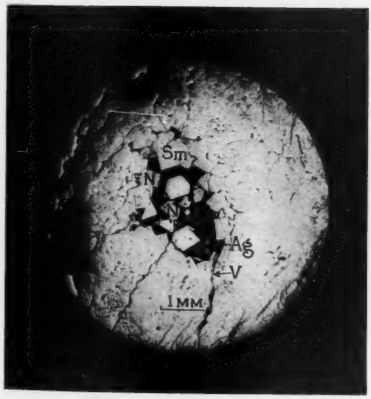


FIG. C.

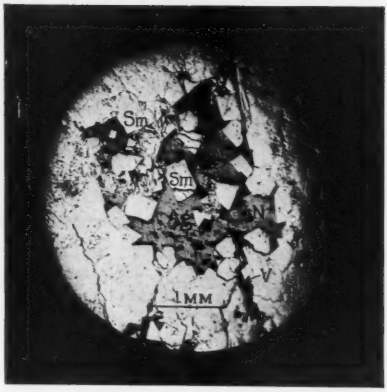


FIG. D.

It is noteworthy that all of the reactions cited liberate sulphuric acid but all may be initiated under neutral as well as acid conditions; the silver sulphate solution used in the experiments was in fact neutral to start with.[23]

The resulting solutions are capable of attacking calcite but neutralization by calcite would not inhibit the deposition of silver so long as any silver sulphate remained in the solutions.

In considering the origin of the rich ores of Cobalt an explanation must be sought not only for the deposition of silver, but also for its solution and its transfer in solution from one part of a lode to another. According to the downward enrichment hypothesis the most available agent for such solution and transfer would be ferric sulphate. The presence of pyrite, chalcopyrite, and arsenopyrite in the ores as well as the presence of notable amounts of iron in smaltite, ferruginous calcite, and probably other minerals, assures the production, through oxidation, of notable amounts of ferric sulphate. Palmer has shown that ferric sulphate may also be formed by the action of silver sulphate solutions on arsenides of iron in the manner exemplified by equations *4a* and *b*, and he has further determined that smaltite from the Buffalo mine at Cobalt contains nearly 8 per cent. of iron, most of which is in a form capable of reacting reducingly on silver sulphate solution. An adequate supply of ferric sulphate seems therefore to be assured.

It remains to account chemically for the formation of replacement veinlets of native silver in ferruginous calcite, one of the commonest phenomena of the Cobalt ores. It is obvious that direct chemical interchanges of the type already described cannot explain these occurrences; but it is apparent that ferrous sulphate is the precipitant concerned. Many tests show that most of the

assign all the remainder of the dissolved arsenic to the cobalt found in the solution. The dissolved substances are, therefore,

Niccolite, .1011 gram, and smaltite, .0137 gram.

This experiment shows that in silver sulphate solution niccolite dissolves more quickly than does smaltite.

[23] According to Palmer (see companion paper), the reaction with löllingite proceeds more rapidly under acid conditions.

calcite of the Cobalt ores is notably ferruginous. Silver-bearing solutions after reacting with simple arsenides in accordance with any one of the above equations would carry sulphuric acid. By subsequent reaction with the ferruginous calcite, this acid solution would create spaces in which silver might be deposited and coincidently ferrous sulphate is formed and this salt is known to be an effective precipitant of silver.

In conclusion, chemical reactions that from experimental results are known to take place if acidic sulphate solutions carrying silver and iron are brought in contact with the minerals characteristic of the Cobalt ores appear adequate to explain all of the replacement phenomena described in this paper. It is probable that few geologists would deny to downward enrichment a rôle in the genesis of the silver ores of Cobalt, Ontario, and similar ores elsewhere. In so far as downward enrichment has been operative it has probably involved reactions of the order here indicated.

The study of reactions that would take place if the same suite of primary minerals were brought in contact with silver-bearing solutions having properties analogous to those of hypogene ore-bearing solutions offers an attractive field for geochemical research.

# THE GEOLOGIC DISTRIBUTION AND GENESIS OF THE METALS IN THE SANTA RITA–PATAGONIA MOUNTAINS, ARIZONA.[1]

FRANK C. SCHRADER.

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[1] Published with the permission of the Director of the U. S. Geological Survey. A fuller account appears in the recently published U. S. Geological Survey Bulletin 582, which is based on a field reconnaissance made by J. M. Hill and the writer.

## LOCATION.

The Santa Rita and Patagonia mountains are situated in southern Arizona in Pima and Santa Cruz counties, and in the Patagonia and Nogales topographic quadrangles of the United States Geological Survey. Forming an irregular belt about eight miles in average width the mountains extend from near the main line of the Southern Pacific Railroad east of Tucson, southward to the Mexican boundary, nearly fifty miles distant. Patagonia, an important distributive and shipping point for mining districts, is located on the Benson-Nogales branch of the railroad where it crosses the south-central part of the range.

## MINING DISTRICTS.

Beginning on the north the range is subdivided into the Empire, Helvetia, Greaterville, Old Baldy, Tyndall, San Cayetano, Wrightson, Red Rock, Harshaw, Palmetto, Patagonia, and Nogales districts, each district having its own several camps or settlements. The chief producers and those in which the mines and deposits are the more abundantly distributed, are the Helvetia, Empire and Greaterville districts on the north, the Tyndall district, on the west-central slope of the range, and the Harshaw and Patagonia districts on the south.

## SURFACE FEATURES.

The mountains are of the Great Basin type. On either side they overlook broad detritus-filled valleys. They are mostly rugged and near the center of the range culminate in Old Baldy, a knoblike peak at 9,432 feet in elevation or about 7,000 feet above the adjoining Santa Cruz Valley on the west. Longitudinal faulting has played an important part in the orogeny. The gentler slopes are on the east, the scarps and steeper slopes on the west.

The mountains form a nearly continuous range, though toward the south they are traversed by the trenchant valley of Sonoita Creek. The portion to the north of the valley is known as the Santa Rita and that to the south as the Patagonia Mountains.

The mountains are drained by the Santa Cruz River, which flows northward into the Gila.

## GEOLOGY.

The range consists of a granitic axis of probable pre-Cambrian age, flanked by overlapping and locally highly tilted Cambrian ? to Cretaceous sedimentaries, which except the Cretaceous have been invaded by Mesozoic intrusives and all covered by Tertiary volcanics. The structure in general is monoclinal with the dip gently to the east and the trend northwesterly. Areally, the igneous rocks are dominant. In a generalized section the principal sediments in natural or descending order are as follows:

SEDIMENTARY ROCKS IN THE SANTA RITA AND PATAGONIA MOUNTAINS, ARIZONA (GENERALIZED SECTION).

| | | | Thickness. |
|---|---|---|---|
| Cenozoic | Quaternary | Alluvium (silts, sands and gravels along present streams) | 100 feet. |
| | | Gravels and sands (valley fill) | |
| Chiefly Mesozoic | Chiefly Cretaceous | Red shales, sandstones and conglomerates (chiefly Comanche series) | 6,000 feet. |
| | Unconformity | | |
| Paleozoic | Carboniferous (Pennsylvanian) | Thin-bedded dark limestones | 4,000 feet. |
| | | Heavy light-colored limestones | |
| | Unconformity | | |
| | Devonian (Middle Devonian) | Thin-bedded gray limestone | |
| | Unconformity | | |
| | Cambrian? | Conglomerate, Quartzite, Shale, Schist | 4,000 feet. |

Economically, the most important of the sedimentary rocks are the Paleozoic limestones. They occur in relatively moderate-sized areas throughout the range and are locally highly altered by contact metamorphism. In a few instances, as at the

Flux mine, near Patagonia, and at the Duquesne-Washington camp, the limestones have been largely engulfed by the invading magmas.

The principal igneous rocks in partial columnar and age order, beginning with the youngest, are as follows:

IGNEOUS ROCKS IN THE SANTA RITA AND PATAGONIA MOUNTAINS, ARIZONA.

| | | | | Thickness. |
|---|---|---|---|---|
| Lava flows | Quaternary | Basalt | | 6 feet. |
| | Tertiary | Tuffs and agglomerates<br>Rhyolite<br>Andesite<br>Quartz latite porphyry<br>Rhyolite | | 2,500 feet. |
| Granitic intrusives | Mesozoic | Acidic | Rhyolite porphyry<br>Aplite and aplitic rocks<br>Granite porphyry<br>Younger quartz monzonite<br>Quartz diorite<br>Older quartz monzonite<br>Granite | |
| | | Basic | Diabase<br>Gabbro<br>Syenite rocks<br>Lamprophyric dike rocks | |
| Pre-Cambrian? | | | Granite (basal) | |

Of the igneous rocks the Tertiary effusives are most abundant. They occur in areas ranging up to 10 miles or more in extent and cover most of the south-central part of the range They consist chiefly of normal rhyolites and andesites with associated tuffs and breccias and occur as heavy flows and beds; in the vicinity of Old Baldy a thickness of 2,100 feet is exposed. To the southwest near the Alto mine in the Tyndall district effusive features are not so marked and the quartz latite assumes a holocrystalline texture.

In places, the lavas are hydrothermally altered by sericitization, silicification, and propylitization.

The most important of the igneous rocks, however, with reference to the ore deposits are the Mesozoic acidic intrusives. These granitic rocks seem to have a common origin and probably represent differentiations of the same mother magma. They

include masses of intermediate composition and range from quartz diorite through quartz monzonite and granodiorite to granite. A petrographic characteristic running throughout the series is the monzonitic or dual feldspar feature of their composition.

The rocks occur as stocks, dikes and small batholithic masses, which range up to twenty miles in length. The most abundant and important are the granite, quartz diorite, quartz monzonite, and granite porphyry. Areally they occur in about equal amount.

The granite occurs chiefly in the northern part of the range in the Empire, Helvetia, Greaterville, Old Baldy, and Tyndall districts, the quartz diorite in the west-central part in the Tyndall district and the quartz monzonite and granite porphyry in the southern and south-central parts in the Patagonia, Palmetto, and Harshaw districts. Some younger quartz monzonite is also associated with the quartz diorite in the west-central part in the Tyndall district.

*Granite.*—The granite in general is a reddish coarse to medium-grained, somewhat porphyritic rock. It is composed principally of orthoclase (or microline), quartz, and biotite, but also contains oligoclase, hornblende and a little augite. Apatite, zircon, and magnetite occur sparingly as accessories and in places also pyrite and chalcopyrite.

*Older Quartz Monzonite.*—The older quartz monzonite as seen in the Duquesne-Washington camp is a greenish-gray, black-spreckled granitoid rock with a reddish tinge and weathers reddish brown. It is medium to coarse grained and locally porphyritic. It is fairly fresh and is composed principally of oligoclase-andesine, quartz, orthoclase, biotite, hornblende, augite, and magnetite and contains considerable pyrite and some titanite. The plagioclase, which is the main constituent of the rock, is especially fresh.

*Quartz Diorite.*—The quartz diorite is important economically in that it contains more mineral deposits than any other formation. It contains nearly all the deposits in the Tyndall and

Wrightson districts and in the southwestern part of the Old Baldy district. It is a dark iron-gray massive fine to medium-grained granitoid rock, with usually a pinkish or reddish hue. It is composed principally of oligoclase-andesine with subordinate brown biotite, mostly altered to pale-green chlorite, a nearly equal amount of hornblende, a moderate amount of orthoclase and quartz, nearly all interstitial, a little augite, considerable magnetite, and accessory pyrite, apatite and titanite.

In some localities the rock contains considerable tourmaline and much magnetite, as at the McCleary mines, in the Old Baldy district. In the uncommon basic forms, which approach gabbro, the plagioclase ranges to labradorite, augite is the principal mafic mineral, and the orthoclase and quartz become relatively inconspicuous or absent. A native silver-bearing augite diorite in the west-central slope of the range described by Bond[2] seems to belong to this facies, and certain iron ore deposits described later in the Patagonia district seem to represent still more basic magmatic differentiations of this rock.

*Younger Quartz Monzonite.*—Microscopic examination of specimens collected at points well distributed throughout the diorite belt shows that much of the rock which cannot well be differentiated from the diorite in the field is a quartz monzonite similar to the older quartz monzonite above described. It differs macroscopically however from the older quartz monzonite in being finer grained and less granitoid.

In places it is medium grained and reddish gray, has a crude or indistinctly banded structure, and macroscopically shows considerable biotite. The microscope shows it to be composed principally of oligoclase-andesine and orthoclase in about equal amount, biotite, mostly in large foils, and a subordinate amount of quartz, with a little hornblende, magnetite and pyrite.

*Granite Porphyry.*—Granite porphyry and aplite or their allied forms occur in an extensive series of variations, and some forms have undergone pronounced alteration by silicification and other processes.

[2] Bond, Josiah, "A Silver-bearing Diorite in Southern Arizona," *Eng. and Min. Jour.*, Vol. 39, p. 1268, 1910.

The rocks range from typical granite porphyry and aplite to those composed almost wholly of quartz with only very minor amounts of feldspar. They are widely distributed in small stocks and radial dikes intruded into the pre-Mesozoic, rarely into the Mesozoic, sediments; also into the granite, and to a less extent into the quartz monzonite and diorite.

The granite porphyry is a light-colored coarsely porphyritic granitoid rock composed chiefly of phenocrysts of feldspar, mainly orthoclase, and of quartz, and locally biotite or muscovite, embedded in a finer granitic or microcrystalline groundmass which is likewise composed mostly of orthoclase and quartz. Apatite, zircon, pyrite, cupriferous pyrite and titanite occur as accessories. The rock is locally pegmatitic and has an agglomerate-like structure, and some of it is graphic.

The rock is widely distributed and occurs in nearly all the districts. It comprises many types and is generally associated with ore deposits. A prominent exposure containing numerous prospects occurs two miles east of Helvetia in the form of a stock about a third of a mile in diameter. In the western part of the Harshaw district and adjoining portions of the Palmetto district it occupies about 9 square miles and contains the principal mineral deposits in this part of the range, including those of the Three R, Thunderer, Standard, Sunnyside, and other mines.

*Aplite and Aplitic Rocks.*—The granitic intrusives and surrounding Paleozoic sediments in various parts of the range are cut by many dikes and some small stocklike masses of rock. They are reddish or flesh colored, fine to medium granular, and are composed almost wholly of orthoclase and quartz, a little sodic plagioclase, and a negligible amount of muscovite, biotite, or other dark minerals, with zircon and apatite usually present as accessories. The alkalic feldspar may be represented in part by microline or microperthite or both. In places these rocks are slightly prophyritic and contain glassy-faced phenocrysts of the feldspar.

From the typical aplite thus described these rocks, according

to their mineral composition, range on the one hand through granitic aplite to aplitic granite or even to granite, and on the other through alaskite aplite, alaskite, and alaskite porphyry to almost pure quartz.

*Rhyolite Porphyry.*—Dikes of rhyolite porphyry regarded as probably Mesozoic and which may be a magmatic differentiation phase of the granite porphyry, in places cut the Paleozoic sedimentaries and the intrusive granite as at the Copper Camp in the Empire district and the granite in the Old Baldy and Tyndall districts.

*Rock Alteration.*—Many of the acidic intrusive rocks are altered by development of sericite, quartz, sulphides, alunite, epidote and chlorite.

## THE METALS AND METALLIFEROUS DEPOSITS.

The valuable metals in the deposits of the range are gold, silver, copper, lead, zinc, iron, tungsten and molybdenum. There are about a thousand small mines and prospects scattered throughout the mountains, their character and distribution depending in large measure upon the rock formations in which they occur, and the rocks with which they are genetically associated. Most of the deposits were examined and data collected adequate to show the approximate distribution of the deposits and their metals in each rock formation.

GEOLOGIC DISTRIBUTION OF THE METALLIFEROUS DEPOSITS IN THE SANTA RITA AND PATAGONIA MOUNTAINS, ARIZONA.

| Rock formation or group. | Per cent. of deposits. | Per cent. of the deposits genetically connected with later intrusive rocks. |
|---|---|---|
| Quartz diorite | 30 | 14 |
| Paleozoic sedimentary rocks | 25 | 25 |
| Granite | 10 | 4 |
| Older quartz monzonite | 8 | 5 |
| Granite porphyry | 10 | 2 |
| Younger quartz monzonite | 3 | 2 |
| Tertiary volcanics | 14 | 2 |
| | 100 | 54 |

The lower limit of the oxidized zone is irregular and ranges from less than 100 to 300 feet in depth, but sulphides are usually near the surface. Water occurs in most of the mines and ground water level stands at depths of about 250 feet. The surface deposits yielded chiefly rich silver ores, but in depth the deposits gave way to ores of copper, lead, and zinc. The primary ore minerals are mainly pyrite, galena, argentite, chalcopyrite, tetrahedrite, gold, and sphalerite. Much of the pyrite is cupriferous, much is auriferous and some of it as well as the chalcopyrite and tetrahedrite seems to be also argentiferous. The galena generally is argentiferous and some is also auriferous. Much of the argentite apparently contains gold. The deposits occur chiefly as fissure veins but also as replacement, contact metamorphic, and shear zone, deposits. The term replacement deposits as used in this paper refers to replacement deposits formed at lower temperatures than the contact metamorphic deposits.

The main gangue minerals in the veins are quartz, barite, fluorite, rhodochrosite, and other carbonates.

Important agencies in determining the position of the deposits were the intrusion of the igneous masses along the contact zone, faulting and contraction of the igneous masses on cooling by means of which channels in the form of fissures, shear zones, shrinkage cracks, and joint planes, were opened up. These permitted circulation of the ore-bearing solutions and furnished repositories for the ores. The importance of these fractures is emphasized in the quartz diorite which, though normally a tight and unpromising looking rock for mineral, contains more deposits, mines, longer and larger veins, than any other formation. Secondarily, barrier reefs or sills have also played an important part in arresting, or otherwise influencing the circulation of the depositing solutions.

Potent agencies in determining the metallic nature of the deposits were: (1) the character of the host rock, and (2) the character of the mineralizing solutions; (3) conditions of temperature and pressure.

The deposits occur in two large and contrasting groups that

differ in age and represent at least two distinct periods of mineralization. The older and more important group occurs in association with the Mesozoic granular intrusives and in part with the Paleozoic sedimentary rocks, and is of Mesozoic (probably early Cretaceous) age. The younger group occurs in or associated with the Tertiary volcanic rocks and is of Tertiary age.

*Older Deposits (Cretaceous).*

The older deposits first attracted attention to the mineral wealth of the area and have furnished most of its production. They embrace the larger number of the deposits of the area and are widely distributed thoughout the range.

They contain gold, silver, copper, lead, zinc, iron, tungsten, and molybdenum. As they nowhere occur in the known Cretaceous rocks of the area they are here referred to the early Cretaceous.

These deposits seem to belong to the same general period as the batholiths of California and western Nevada with whose intrusion ore deposits have been widely formed. They were probably deposited chiefly by ascending thermal solutions that circulated as a close after-effect of the intrusion of the Mesozoic magmas.

The older deposits are mainly fissure veins and contact metamorphic deposits, but also replacement and shear zone deposits. They have suffered considerable erosion, and their general nature, together with the alteration of the intruded sedimentary rocks, and the relative coarse texture of the granites at or near the contact, leads to the inference that as a whole the deposits were probably formed originally at considerable depth in the deep vein zone. Also the presence of considerable tourmaline and molybdenite and the occurrence of pegmatite in places point to the magmatic origin of the mineralizing solutions. These conditions denote that at least some of the deposits were formed at high temperatures, and that pneumatolytic action played a part in their genesis.

*Deposits in Sedimentary Rocks.*—The deposits in the sedimentary rocks occur almost entirely as contact metamorphic de-

posits and ordinary replacement deposits, and excepting a few of minor importance found in the Cambrian sediments, are found in the Paleozoic limestone. They seem to be genetically connected with the igneous intrusives about as follows:

| | Per Cent. |
|---|---|
| Granite | 40 |
| Aplite | 20 |
| Granite porphyry | 18 |
| Rhyolite porphyry | 7 |
| Older quartz monzonite | 6 |
| Lamprophyric rocks | 5 |
| Diabase | 1 |
| Diorite | 1 |

*Contact Metamorphic Deposits.*—The contact metamorphic deposits comprise nearly all the deposits in the sedimentary rocks. They were among the first to be formed as they, and the Paleozoic sedimentary and Mesozoic intrusive rocks with which they are connected, are cut by later veins and associated complementary dikes. They are also slightly earlier than the ordinary replacement deposits which generally adjoin them. In this group belong most of the copper deposits in the Helvetia and Empire districts, and also those of the Duquesne-Washington camp in the Patagonia district, described by Professor Crosby.[3]

The deposits occur principally in or near the contact zone of the Paleozoic limestone with the Mesozoic intrusive rocks, particularly the granitic rocks. Along this zone which ranges up to 200 feet or more in width, their formation was accompanied by contact metamorphism, mineralization, and the development of a garnetiferous zone with the usual assemblage of a dozen or more contact minerals. Among the minerals observed mostly in the Duquesne-Washington camp are garnet (andradite and grossularite), pyroxene (diopside, wollastonite, and hedenbergite), amphibole (hornblende, tremolite, actinolite, and gedrite), calcite, dolomite, quartz, epidote, pyrite, magnetite, pyrrhotite, specularite, ilmenite, molybdenite, arsenopyrite, tourmaline, and others.

[3] Crosby, W. O., "The Limestone-granite Contact-deposits of Washington camp, Arizona," *Trans. Amer. Inst. Min. Eng.*, Vol. 36, p. 626, 1906.

These minerals are mostly exomorphic but some are also endomorphic, especially those of the amphibole group. The following is an analysis of a specimen of garnet from the Empire mine which seems to be representative of the garnet in the Duquesne-Washington camp. It shows it to be the calcium-iron variety, andradite. Mineralogically, the garnet is an aluminous andradite and is found by molecular calculation to consist of an isomorphous mixture of about 85 per cent. andradite and 15 per cent. grossularite.

ANALYSES OF GARNET (ANDRADITE).

(From the Empire mine, Duquesne, Ariz., W. T. Schaller, analyst.)

| | |
|---|---|
| $SiO_2$ | 37.16 |
| $Al_2O_3$ | 3.47 |
| $Fe_2O_3$ | 28.11 |
| CaO | 30.23 |
| MgO | .51 |
| FeO | None |
| MnO | Present |
| | 99.48 |

The deposits occur in irregular bodies in a zone from 1 foot to 40 feet or more in width, principally in the Carboniferous limestone. They are mainly copper-bearing, but they generally contain a little silver and gold and some of them also lead and zinc. The chief primary ore minerals are chalcopyrite and cupriferous pyrite, together with a subordinate amount of galena, sphalerite, argentite, pyrrhotite molybdenite, and gold. These sulphides generally appear at or near the surface, but the oxidized zone, which extends to depths of 200 to 300 feet, contains also secondary or oxidized minerals, particularly the common carbonates and oxides of copper, manganese and iron, chloropal, silver chloride, chrysocolla, etc., and the secondary sulphides chalcocite, chalcopyrite, and bornite. To this class belong most of the productive copper deposits which have been worked and have yielded nearly all the copper production especially in the Helvetia and Duquesne-Washington camps. The present workable deposits are apparently chiefly the result of concentration or secondary

enrichment. They consist of malachite, azurite, chalcocite, chalcopyrite, chalcanthite, etc., derived from the chalcopyrite and cupriferous pyrite which occur as contact-metamorphic minerals and as primary or accessory constituents in the intrusive granitic rocks.

The deposits were formed in part directly by magmatic influence of the molten batholith or stock in its peripheral contact with the limestone and other sedimentary rocks, but mainly by the accompanying hydrothermal solutions and pneumatolytic activities that replaced the limestone depositing therein the ores and their associated minerals.

A conclusion reached in the study of this class of deposits is that the intrusive rocks and the attending solutions, especially in the Duquesne-Washington camp, were the principal contributors to the ferruginous mineral constituents of the contact zone, as well as bearers of the ore minerals. It is also concluded that the metallic materials were not derived in any considerable amount from the surrounding limestone nor for any great extent beyond the contact-metamorphic zone. This is indicated on the one hand by the purity of the bordering limestone and by its wholly unaltered condition at many places very near the contact, and on the other hand, by the abundance of silica and ferruginous minerals. The only possible source adequate to account for the silica and iron seems to be the intrusive older quartz monzonite. This, being rich in biotite and hornblende and containing considerable augite and magnetite and some pyrite, could readily supply the iron element, for whose concentration in the deposits the fluid magma and its accompanying hydrothermal solutions and pneumatolytic gases, containing the ingredients, were admirably adapted. The abundant quartz occurring in or associated with the deposits and the metamorphic zones is largely accounted for by the siliceous character of the quartz monzonite magma. This conclusion essentially agrees with the conclusions of others who have investigated similar deposits.[4]

[4] Stewart, C. A., "The Geology and Ore Deposits of the Silver Bell Mining District, Arizona," *Trans. Amer. Inst. Min. Eng.*, Vol. 43, pp. 240–288, 1913.

Similar, though not so marked metamorphic phenomena prevail in the Helvetia and other camps where deposits likewise occurring in the Paleozoic limestone owe their origin to the granite, granite porphyry, aplites and alaskitic rocks. In the Empire district, granite, and rhyolite porphyry in the form of dikes appear to be genetically associated with the deposits.

*Replacement Deposits.*—The replacement deposits are commonly associated with the contact-metamorphic deposits but are apparently in most cases later in age. Like the contact-metamorphic deposits they occur mostly in limestone in association with the intrusive rocks. In some cases they are difficult to differentiate from the contact-metamorphic deposits, since all gradations occur between the two. Mineralogically, however, they are without the characteristic contact-metamorphic minerals and generally they differ from the contact-metamorphic deposits in their metalliferous content. Instead of copper, as in the contact deposits, their principal metallic constituents are lead and silver, and among the secondary minerals are the common oxides of manganese and iron, siderite, jarosite, vanadinite, and wulfenite.

To this class apparently belong in large part the important deposits at the Mowry mine in the Patagonia district, the Total Wreck mine in the Empire district, and the Flux mine in the Harshaw district and some of the mines at Helvetia.

The Mowry deposits produced lead and silver to the value of 1½ million dollars in the early 60's and have since been worked intermittently with good results. They are situated on a fault fissure contact of quartz monzonite and Pennsylvanian limestone. The quartz monzonite is regarded as intrusive into the limestone which is locally altered to fine-grained marble, but the usual metamorphic minerals and silication phenomena are absent. The limestone dips steeply away from the contact and at a depth of

Spurr, J. E., Gerry, G. H., and Fenner, Clarence N., "Study of a Contact Metamorphic Ore Deposit, the Dolores Mine at Matehuala, S. L. P. Mexico," Econ. Geology, Vol. 7, pp. 444–484, 1912.

Umpleby, J. B., "The Genesis of the Mackay Copper Deposits, Idaho," Econ. Geology, Vol. 9, No. 4, pp. 307–358, June, 1914.

about 350 feet in the mine it is underlain by an altered basic rock corresponding to gabbro which also seems to be intrusive.[5]

The ore deposits are best developed in the limestone next to the quartz monzonite. They extend as upright tabular bodies in more or less solid form 600 feet or more along the contact and 100 feet laterally into the limestone. Beyond this occur inclined ore beds or sills ranging up to 20 feet in thickness dipping conformably with the bedding of the limestone.

The deposits consist mainly of lead and silver minerals, such as galena, cerusite, anglesite, and bindheimite, all contained in a manganiferous–ferruginous gangue composed principally of massive psilomelane, pyrolusite and hematite. The manganese and iron together form about one fifth of the ore bodies in volume. There is but little quartz and a remarkable feature is the absence of zinc, especially as zinc is a common mineral in the neighboring mines. The ore is mostly oxidized down to or below the 300-foot level. Scarcely any sulphide other than galena was found above this level. Copper anl iron sulphides first appeared on the 400-foot level where also vanadinite and arsenopyrite sparingly occur.

The Mowry deposits seem to have been formed by metasomatic replacement through the agency of mineral-bearing solutions that circulated along the contact fault. The ore deposition extended from the monzonite contact into the limestone. The solutions were probably thermal and deposited the ore minerals at considerable depth in the limestone, chiefly as sulphides of lead, silver, iron, and manganese. Subsequently, in the lowering of the surface by erosion these sulphide ore minerals became oxidized and concentrated to their present state. Silver leached from the overlying now eroded deposits doubtless contributed to their enrichment.

Inasmuch as the Mowry rocks and ores are similar to those of Leadville, Colo.,[6] a similar origin may be ascribed to them.

[5] Data on the lower levels of the mine, which were under water at the time of visit, were kindly supplied by the Mowry Mines Company.

[6] Argall, Philip, "Siderite and Sulphides in Leadville Ore Deposits," *Min. and Sci. Press*, Vol. 109, pp. 50–54 and 128–135, July–December, 1914.

Thus it is concluded that the quartz monzonite at Mowry is the probable source of the deposits.

*Vein and Shear Zone Deposits.*—Vein deposits in the sedimentary rocks are few and are usually associated with contact-metamorphic deposits, where they occupy small fissures of apparently the same class as those occupied by complementary dikes of the main intrusive. Some, however, occur in the Paleozoic rocks away from contacts and in connection with rhyolite porphyry and lamprophyric dikes. The deposits of the Verde Queen and Chief mines in the Empire district are examples of these. The metals are chiefly copper and lead, with minor quantities of gold and silver. A few deposits also occur in the Cambrian ? schist and quartzite where, as in the later Paleozoic rocks, the principal metalliferous content is copper and the deposits are genetically closely connected with lamprophyric intrusives; the deposits of the Lucky Ledge and other mines in the Old Baldy district are examples of this class.

*Deposits in the Acidic Intrusive Rocks.*—The deposits in the intrusive rocks occur almost wholly in those of acidic character. They are found in all the acidic rocks but are relatively more plentiful in the quartz diorite, as in the Tyndall district, and the granite porphyry and quartz monzonites, as in the Palmetto district, than in the other formations. They occur chiefly as fissure veins but also as shear zone and replacement deposits.

The deposits probably owe their origin to solutions which circulated through the fissures following the intrusion of the inclosing rocks, or of closely connected complementary dikes. In some instances the presence of considerable tourmaline and molybdenite point to the magmatic origin of the mineralizing solutions, and suggest that certain of the deposits have been formed at high temperatures.

In the fissure vein and shear zone deposits, where the gangue is siliceous, the principal primary ore mineral is generally galena but where the gangue is basic or composed chiefly of crushed or sheared rock as at the Three R mine, chalcopyrite and other copper-bearing minerals predominate. This is especially true in

the quartz diorite and the monzonites. These conditions are essentially in harmony with those that prevail in the granite, where the deposits are mostly siliceous and the dominant metals are lead, gold, and silver.

*Veins.*—The veins are numerous and widely distributed. They are particularly plentiful on the west slope of the Santa Rita Mountains and in the Patagonia Mountains. They range from 1 foot to 20 feet or more in width, 6 feet being perhaps the average width, and they are commonly separated from the wall rock by a few inches to a foot or more of kaolin gouge. In places they parallel the dominant jointing or fault system, with steep or vertical dips, but more commonly they occupy independent cross or diagonal fissures and in a general way lie approximately parallel with the axis of the range. Many are persistent, some have a length of a mile or more and a known vertical range of nearly 1,000 feet, and some have been opened to the depth of 500 feet. They occur mostly in fault fissures but some appear to occupy shrinkage cracks due to contraction of the rock on cooling. The croppings are frequently prominent and consist chiefly of vein quartz and altered silicified rock heavily stained with oxides of iron and manganese, copper, and lead carbonates.

The gangue or filling of the veins is chiefly quartz, with fluorite and barite. It frequently contains rhodochrosite and in a few mines magnetite is the dominant constituent. The primary ore minerals are chalcopyrite, cupriferous pyrite, pyrite, galena, argentite, native silver, gold, tetrahedrite, bornite, arsenopyrite, sphalerite, specularite, siderite, molybdenite, wolframite, and scheelite.

The deposits also contain oxidized minerals, such as cerargyrite, bromyrite, stephanite, pyromorphite, cerusite, anglesite, malachite, azurite, chalcanthite, native copper, psilomelane, pyrolusite, hematite, limonite, bindheimite, utahite, and others, and the secondary sulphides, chalcocite, chalcopyrite, bornite, and covellite.

In places the ore is not restricted to the fissure but extends in

irregular bodies laterally several feet or more into the wall rock. This has locally been metasomatically replaced and silicified by the ore-bearing solutions, and the deposits thus merge into those of the replacement type, later described.

The distribution of the deposits in any given formation is largely dependent upon the location of fissures and other openings that afforded channels and repositories for the depositing solutions. The deposits are more numerous at or near the margin of the host formation which represents the zone of maximum fracturing and lower temperature and pressure, and consequently that of maximum circulation and precipitation. This is shown in the quartz diorite along its north contact with the granite in the Tyndall district; also in a narrow belt of the same rock in the Old Baldy district, and to some extent in several areas of granite porphyry in the southern part of the range. It is also noticeable in several instances that smaller areas or stocks particularly of granite porphyry in the Helvetia and Tyndall districts contain more deposits in proportion to their size and periphery than larger areas.

Away from the marginal zone of fracture and segregation the deposits are sporadically distributed. For instance, the Tia Juana vein from 10 to 40 feet in width and 2½ miles in length lies in the center of a large area of quartz diorite 4 miles in width.

*Shear Zone Deposits.*—The shear zone deposits occur in the same formations as the fissure veins, and in some cases are associated with them. To this class belong the Florida mine in the Old Baldy district and the recently notably productive Three R mine near Patagonia, both copper mines. In the Three R mine the shear zone, which is from 40 to 100 feet in width, lies in granite porphyry heavily impregnated with pyrite, and a little chalcopyrite. Within the zone there is a concentration of these minerals forming crude stock works or bunches of ore and veins in the sheared and altered rock. In the deeper part of the mine there have been concentrated by processes of secondary enrichment bodies of workable ore consisting of chalcocite, bornite,

chalcopyrite and covellite, replacing the sheared and altered alunitized rock; below these secondary ores lies the zone of primary sulphides.

The progress of enrichment, as shown by microscopic study of ores from this mine by Graton and Murdoch,[7] consists of several steps approximately in the order of bornite, covellite, chalcocite, and chalcopyrite, though all of these minerals are not invariably present. With this process the results of later studies made by Probert[8] in the mine essentially agree.

*Deposits in the Granite.*—In the granite which is exposed mainly in the Empire, Helvetia, Greaterville, Old Baldy, and Tyndall districts, the deposits occur mostly in quartz veins or siliceous shear zones and contain chiefly lead, gold, and silver. but sometimes copper and molybdenum in workable amount. Few of the deposits appear to have genetic connection with later rocks such as granite porphyry, aplite, diorite, and rhyolite porphyry which are intruded in the granite.

The primary ore minerals are galena, argentiferous galena argentite, pyrite, chalcopyrite, sphalerite, and free gold, more rarely tetrahedrite. The most important secondary or oxidized minerals are cerargyrite, cerusite, copper carbonates, and in a few cases zinc carbonate. Gold and silver are both present, one or the other predominating. The gold in the Greaterville placers, which have produced more than $7,000,000 and still contain by estimate much more, seem to have been derived chiefly from this class of deposits which occur in the granite in the adjoining upper slope of the range. In certain instances the granite is probably pre-Cambrian but it could not be differentiated from the Mesozoic rock. The veins are mostly small with low ore tenor in depth and the metallic minerals sporadically distributed in the gangue.

In a few of the deposits which seem to be genetically connected with later intrusives, copper, or copper and lead are the dominant metals, with gold and silver next in importance.

[7] Graton, L. C., and Murdoch, Joseph, "The Ores of Copper: Some Results of Microscopic Study," *Am. Inst. Min. Eng. Trans.*, Vol. 46, No. 77, pp. 754–755, figs. 5 and 6, 1913.

[8] Probert, F. R., "The Three R Mine, Patagonia District, Ariz.," *Min. and Sci. Press*, Vol. 109, No. 5, p. 176, 1914.

Molybdenum stands next to copper and lead in value in the Elephant Head deposits, where they are associated with rhyolite porphyry, and in the Ridley Mine at Helvetia where granite is intruded by aplite dikes. The primary ore minerals are chiefly chalcopyrite, galena and molybdenite. Sphalerite is frequently conspicuous but it is not present in workable amount.

In half a dozen or so of the deposits the only valuable metal is molybdenum. It occurs mostly as flaky pieces of molybdenite associated with a little pyrite and chalcopyrite in quartz veins or stock works. This is especially true in the Old Baldy district, where in some cases the deposits seem to be genetically connected with intrusive aplite dikes.

Though some molybdenite occurs in nearly all the geologic formations of the range the home of this mineral seems to be chiefly in the granite and the older quartz monzonite. It also occurs to a lesser extent in the contact or replacement deposits of the sedimentary formations where intruded by either of these two rocks, as in the Leader mine at Hevetia. A sketch of the general occurrence of molybdenite in the range appears in an earlier paper.[9]

*Deposits in the Older Quartz Monzonite. Vein and Shear Zone Deposits.*—In the older quartz monzonite, found chiefly in the southern part of the range in the Patagonia, Palmetto, and Nogales districts, the deposits occur almost entirely as vein and shear zone deposits. About 60 per cent. of them appear to be genetically connected with later intrusives, of which 50 per cent. is with the quartz diorite, and 10 per cent. with the granite porphyry. Copper is the principal, almost the only metal. Forty per cent. of the deposits contain copper only, the dominant primary ore minerals in nearly all cases being chalcopyrite and pyrite. Bornite and molybdenite are present in some cases in subordinate amount. The gangue minerals are chiefly quartz and calcite, kaolin, brecciated, altered and silicified rock. The secondary or oxidized minerals are chiefly the oxides of iron and

[9] Schrader, F. C., and Hill, J. M., "Some Occurrences of Molybdenite in the Santa Rita and Patagonia Mountains, Arizona," U. S. Geol. Survey Bull. 430, pp. 158–159, 1910.

manganese and the secondary sulphides are chalcocite, chalcopyrite, bornite, and covellite.

In the Patagonia district in the west slope of the Patagonia Mountains in the triangular area occupying a square mile or more bounded by Sycamore Canyon on the south and Providentia Canyon on the northwest, the quartz monzonite is impregnated with uniformly disseminated grains of chalcopyrite, pyrite and bornite, and some molybdenite. These minerals, particularly the pyrite and chalcopyrite, both macroscopically and microscopically seem to be primary, of magmatic origin, and to have crystallized out from the original magma similarly and contemporaneously with the rock minerals. They are very persistent throughout the area and are observed through a vertical range of 800 feet.

In about 30 per cent. of the deposits in the older quartz monzonite lead is the dominant metal with silver or copper next and gold in a few of them. The primary ore minerals are chiefly galena, argentiferous galena, chalcopyrite, pyrite, and argentite. The secondary or oxidation minerals are cerusite, cerargyrite, limonite and manganese dioxide.

In 10 per cent. of the deposits, notably those in the Nogales district at Mount Benedict, the mines are worked for gold. Here the metals in order of importance occur as gold, lead, silver, and copper. The primary ore minerals are pyrite, chalcopyrite, galena, argentiferous galena, argentite, gold, wolframite, and stibnite. The secondary or oxidized minerals are cerargyrite, proustite, pyrargyrite, cerusite, and the oxides of iron and manganese. The gold is mostly associated with the pyrite, chalcopyrite, galena, cerusite, and stibnite.

A few of the deposits contain only lead and silver, the chief ore mineral being argentiferous galena, and a few contain only lead and copper, the ore minerals in this case being galena and chalcopyrite.

In some of the deposits, notably those at the Reagan camp and vicinity in the northern part of the Nogales district, the only important metal is tungsten. This occurs mainly as wolframite and subordinately as scheelite. The wolframite and scheelite

occur in narrow quartz veins contained in dark lamprophyric dikes, and in the adjoining quartz monzonite country rock which the dikes abundantly intrude. A small amount of calcite is present as a primary gangue mineral mingled with the vein quartz. Apparently the only secondary or oxidation mineral present is a little hematite which stains the fissure walls and gouge and in places is pseudomorphic after wolframite.[10]

*Contact-Metamorphic Deposits.*—Ores which may be regarded as a form of contact-metamprphic deposits occur at several localities in the older quartz monzonite where it has been invaded by the younger of the Mesozoic intrusives. Of this class the Line Boy deposit in the southern part of the Patagonia district on the International Boundary is an example. Here, a small stock-like mass of granite porphyry intrudes the quartz monzonite. From the stock a 10-foot dike of the porphyry extends radially outward into the quartz monzonite, which it has sericitized and otherwise altered along the contact. The metallic minerals, pyrite, chalcopyrite, and molybdenite, with a little bornite, calcite and quartz, are abundantly developed along the contact and are concentrated in joint planes and small fissures. The quartz monzonite is partly impregnated with them. Along the hanging-wall side of the dike occurs a sheet of specularite 3 feet wide and a 6-foot vein of copper ore containing principally chalcopyrite with much bornite.

*Deposits in the Quartz Diorite.*—In the quartz diorite, which lies mainly on the central west slope of the range in the Tyndall and Old Baldy districts, the deposits occur mainly as veins with also a few scattering shear zone and replacement types. They contain the metals copper, silver, lead, gold, zinc, molybdenum, and iron. The primary ore minerals are chalcopyrite, galena, argentiferous galena, argentite, auriferous pyrite, molybdenite, magnetite, sphalerite, specularite, bornite, and chalcocite (?). Secondary or oxidation minerals now present are malachite, azurite, chrysocolla, cuprite, cerargyrite, bromyrite, embolite, cerusite,

[10] For a fuller description of these tungsten deposits see Hill, J. M., "Note on the Occurrence of Tungsten Minerals near Calabasas, Arizona," U. S. Geol. Survey Bull. 430, pp. 164–166, 1910.

pyromorphite, anglesite, smithsonite, marcasite, the common oxides of iron and manganese, and the secondary sulphides chalcocite, chalcopyrite and covellite, and stephanite and dyscrasite.

The primary gangue is chiefly quartz and barite, with a little calcite, rhodochrosite, and tourmaline, but in many cases now contains also considerable carbonate, especially manganese and iron, also iron oxides, kaolin, and altered rock material.

The presence of tourmaline common in the Old Baldy district and not rare in the Patagonia district indicates that some of the deposits are of the high temperature type.

In about 50 per cent. of the deposits copper is the dominant metal and in 25 per cent. it is the sole metal. Its most common associate metal is silver, with lead a close second. In a few cases only, gold, silver, or lead is the only associated metal. In about 40 per cent. of the deposits lead is the dominant metal with the second place shared about equally by copper and silver.

In about 10 per cent. of the deposits silver is the dominant metal, and in most of these cases it is associated with lead, the two metals commonly occurring in argentiferous galena. In a few deposits, however, as at the Salero and Montezuma mines the silver occurs chiefly in argentite and cerargyrite with copper as the only associated metal. Zinc, except as an associate metal, is rare, and when present in commercial quantity, it occupies third place with lead and copper.

The few iron deposits in the quartz diorite consist chiefly of massive bodies of magnetite and quartz or of specularite and quartz, as in those of the Specularite Prospect near Gross camp in the Patagonia district, which have been used for flux.

Of the deposits observed in the quartz diorite formation only about 44 per cent. appear to be directly connected genetically with later intrusives. Of these 22 per cent. are associated with granite porphyry, 16 per cent. with rhyolite porphyry, and 2 per cent. each with aplite, younger quartz monzonite, and andesite.

In the deposits associated with the intensive granite porphyry the metals in order of abundance are copper, lead, silver, and gold, with gold in a few cases in the lead. In those associated

with the rhyolite porphyry, the metals are copper, lead, gold, and silver, the two latter occupying subordinate positions. In the deposits associated with the younger quartz monzonite the dominant metals are silver and copper, in those associated with the andesite, silver, gold, lead and copper.

The genesis of deposits apparently not connected with later intrusives such as the Tia Juana vein described on page —, and whose metals are silver, copper, and lead is provisionally referred to mineralizing thermal solutions derived from and circulated as an after-effect of the intrusion of, the quartz diorite magma itself.

*Deposits in the Granite Porphyry.*—In the granite porphyry, found chiefly in the southern part of the range in areas from three to five miles in extent, the deposits are chiefly veins and shear zone replacements, containing copper, lead and silver in the order given. They include those of the Three R mine described on page —, the Happy Jack, Sunnyside, and in part those of the Alto and other mines. In 60 per cent. of the deposits copper ranks first with the second place about equally divided between lead and silver. In 25 per cent. lead holds first place. with silver second, and in 15 per cent. silver is first with copper second. The primary ore minerals are chiefly chalcopyrite, pyrite, cupriferous pyrite, galena, argentiferous galena, tetrahedrite, argentite, and molybdenite. The ores contain also the secondary or oxidation minerals, malachite, azurite, cerargyrite, bromyrite, pyromorphite, the hydrous oxides of iron and manganese, and the secondary sulphides chalcocite, bornite, chalcopyrite, and covellite. The gangue is chiefly quartz and altered rock with barite, alunite, specularite, calcite, other carbonates, and kaolin.

The deposits are rarely connected with later intrusives which seem adequate to account for their origin, though in the Happy Jack mine the enclosing formation is cut by greenish altered dikes which appear to be andesite, and at the Three R mine by light colored aplitic dikes.

The deposits in most cases seem to have been formed by

thermal solutions that were derived from and followed the intrusion of the granite porphyry magma itself. Its favorableness as a repository for workable deposits is largely attributed to its feldspar phenocrysts which, being relatively more soluble with their cleavage edges exposed to attack, stand foremost in affording avenues of penetration for the mineralizing solutions and gases.

*Deposits in the Younger Quartz Monzonite.*—The younger quartz monzonite occurs chiefly as small stocks intruding the older quartz monzonite and the quartz diorite, mostly in the Patagonia and Tyndall districts.

The few deposits in this formation occur chiefly as veins and shear zone replacement deposits. Their dominant metal is copper with gold and silver also present in some veins. The principal primary ore minerals are chalcopyrite, cupriferous pyrite, argentite, and bornite.

The primary minerals also include sphalerite, specularite, magnetite, gold, and molybdenite. The ores contain the usual oxidized minerals and secondary sulphides, chalcocite and chalcopyite.

The gangue is mainly quartz, altered and replaced rock with tourmaline present in places. Among the most important of the deposits are those of the Four Metals and Omara mines in the Patagonia district and the Carrie Nation mine in the Old Baldy district. The Four Metals and Carrie Nation deposits are of the replacement shear zone type.

The Four Metals deposit occurs in a fault shear zone 1200 feet or more in width in which the greatly shattered and altered rock is impregnated and replaced by the deposits, of which the most important occur within a width of 500 feet. Copper is the sole metal of economic importance. The primary and chief ore mineral is chalcopyrite. Some chalcocite, which may be primary, is also present, as are also pyrite and cupriferous pyrite, and a little galena, argentite, and gold. In the Omara deposits which are quartz veins the dominant metal is gold with silver second and copper third.

The depositing solutions may have been derived from the magma of the inclosing younger quartz monzonite itself, which as a small stock intrudes the older quartz monzonite and contains disseminated cupriferous pyrite and chalcopyrite apparently as primary constituents.

*Deposits Associated with the Lamprophyric Rocks.*—Excepting the silver-gold deposits in the Blue Jay mine in the Helvetia district, the only metals observed in or genetically connected with the lamprophyric rocks, which occur chiefly as dikes, are those of copper in the Old Baldy district described under deposits in the sedimentary rocks, and tungsten in the Nogales district described under the older quartz monzonite.

### *Younger Deposits (Tertiary).*

The younger group of deposits occurs in or associated with the Tertiary effusive volcanic rocks which occupy most of the south-central part of the range. Excepting a small belt of quartz latite porphyry covering about 8 square miles in the Tyndall district on the west, the rocks are almost entirely andesite and rhyolite, which occur in approximately equal amount and are disposed in large areas. The rhyolite is the older formation but the andesite is locally cut by dikes of a younger rhyolite. About 50 per cent. of the deposits occurs in the andesite, 40 per cent. in the rhyolite, and 10 per cent. in the quartz latite porphyry.

This group of ore deposits is regarded as late Miocene and possibly Pliocene. It belongs to the late Tertiary epoch of metallization and to the great group of metalliferous deposits in the Tertiary volcanic rocks throughout the west, formed near the surface by ascending thermal solutions.

*Veins.*—The deposits occur in irregular and branching veins which are chiefly fissure veins, and also to some extent as replacement deposits. The great group to which they belong is in general throughout the west gold-silver-bearing quartz veins. In the present region, however, the deposits are chiefly base metal veins and contain principally copper, lead, silver, and gold; in

this respect similar to certain deposits described by Purington and others in the San Juan region, Colorado.[11]

The gangue is mostly quartz but it frequently contains also barite, fluorite, calcite, rhodochrosite, rhodonite, and altered and replaced rock, kaolin, and occasionally epidote and gypsum.

The primary ore minerals are chalcopyrite, pyrite, tetrahedrite, bornite, chalcocite, galena, argentiferous galena, argentite, proustite, sphalerite, molybdenite, specularite, and gold. Secondary or oxidation minerals contained in the ores are malachite, azurite, chrysocolla, cuprite, tenorite, cerargyrite, bromyrite, embolite, wulfenite, cerusite, marcasite, and the secondary sulphides chalcocite, chalcopyrite, and bornite.

A constancy in association of certain minerals giving rise to two types of veins is noticeable. These types are (1) tetrahedrite-rhodochrosite veins, and (2) quartz-galena-sphalerite ? veins. In the first type usually rhodochrosite, and in some instances rhodonite, is present in deposits in which tetrahedrite is a leading or an important ore mineral, as in those of the Jersey Girl and other prospects.

In the second type, which are quartz-galena veins, sphalerite is present but rarely in commercial quantity.

Though these types of deposits may not be identical to those of the "tetrahedrite-rhodochrosite veins" and the "quartz-galena zincblende veins" of the Lake City district, Colorado, described by Irving and Bancroft,[12] and later discussed by Lindgren,[13] their general similarity to them is very marked.

The deposits of the group are numerous and relatively but little developed. About a score, however, have become producers, among them the Rhode Island, La Plata, Gringo, and other important mines.

In more than 50 per cent. of the deposits the dominant metal is

[11] Purington, Chester W., U. S. Geol. Survey Geol. Atlas, Telluride Folio (No. 57) and folios Nos. 60, 120, 130, 131, 153, and 171 in the San Juan region, Colorado.

[12] Irving, J. D., and Bancroft, H., "Geology and Ore Deposits near Lake City, Colorado," Bull. U. S. Geol. Survey No. 478, p. 47, 1911.

[13] Lindgren, Waldemar, "Mineral Deposits," p. 505, 1913.

copper, in 25 per cent. silver, in 17 per cent. lead, and in 7 per cent. gold. Gold is present in 25 per cent. of the deposits and in a few, as those of the Gringo and Silver Cave mines in andesite and the Helena mine in rhyolite, it is the only workable metal.

In the deposits in andesite taken as a whole the rank of the metals is copper, lead, silver, and gold, with copper dominant in about 50 per cent., silver and lead in 25 per cent., and gold in 20 per cent.

In the deposits in rhyolite, copper is the dominant metal in nearly every case, with silver and gold, rarely lead, occupying second place. In several cases copper is the sole metal and in a few cases silver and gold, rarely lead, each stand first.

In the quartz latite porphyry, copper is the dominant metal in about 60 per cent. of the deposits, with silver and lead each in 20 per cent., gold and zinc occurring only as subordinate or associate metals.

From the foregoing description it appears that copper shows a decided preference for the rhyolite as does also, to a less extent, silver and gold. The same, excepting gold, is to a less extent true for the quartz latite porphyry, while lead appears to find its best repository in the andesite. Aside from these preferences the deposits do not seem to be dependent upon any particular kind of rock or formation nor do they seem to be dependent upon intrusives.

The deposits seem to have been formed by ascending thermal solutions which circulated mainly as a close after-effect of the eruptions of the containing lavas themselves. They were formed in fissures and fractures that resulted from the effects of volcanism or post-volcanic crustal adjustment and contraction of the lavas upon cooling. Their distribution in the volcanic rocks has accordingly been determined chiefly by the more or less accidental position of fissures and fractures that were accessible to the depositing solutions. A subordinate, though in some instances, an important feature was the lower temperature which accelerated precipitation and deposition from solutions that circulated in the more rapidly cooling border zone of the lavas,

particularly where they lay in contact with the older formations. This is illustrated by the marginal position of many deposits, for instance, in the quartz latite porphyry in the Tyndall district, where this rock is in contact with and locally intrudes the granite porphyry just west of the Salero and Alto camps, and the quartz diorite farther north toward Josephine Canyon.

*Replacement Deposits.*—The replacement deposits belonging to the Tertiary group occur in two forms, (1) ore beds, and (2) replacements adjoining fissure veins.

1. *Ore Beds.*—The ore beds occur in certain flows and intrusive sheets of the lavas notably of the rhyolite. Of those occurring in flows, the deposits a few miles south of Patagonia furnish good examples. Here over a wide area the rhyolite composing Red Mountain and the surrounding region is heavily impregnated with pyrite, and chalcopyrite, both of which seem to be primary. The weathered surface of the rock is often coated with malachite, chalcocite, and bornite. For instance, at the Invincible mine in which the valuable metal is gold in quartz veins, concentrates from the enclosing pyritic rhyolite were found to average 3 per cent. in copper, 33 per cent. iron, and 35 per cent. sulphur.

On the Aztec ground the copper minerals, notably chalcocite, chalcopyrite, bornite, and malachite, are particularly concentrated as replacement deposits, probably in part by processes of secondary enrichment, in a 12-foot wide replacement body. In the bed some of the ore is banded and consists of tabular shoots or veins an inch in width composed of relatively pure chalcocite and chalcopyrite.

In the Morning Glory mine in the Patagonia district the so-called vein having a dip of 40° appears to be a replacement ore bed representing an 8-foot sheet or sill of rhyolite intruded into the Paleozoic limestone. The ore minerals are chiefly pyrite and chalcopyrite with some sphalerite and a little hematite and specularite. The gangue minerals consist of quartz, a little calcite, and barite. Chalcocite is sparingly present as a secondary sulphide. The dominant metal is copper, with also silver and zinc present in workable amount.

In replacement deposits, similar to those of the Morning Glory mine, occurring in sheets of rhyolite similarly intruding quartzite and shale in the Harshaw district, at the Hardshell, Hermosa, and Salvador mines, the metals are respectively lead and silver, or silver alone.

2. *Replacements Adjoining Fissure Veins.*—The replacements adjoining fissure veins consist of deposits which have metasomatically replaced the adjoining wall rock. They are irregular especially in lateral extent and contain essentially the same class of ore and minerals as the vein. The gangue is generally siliceous and the veins are enclosed by silicified or propylitically altered wall rock. The Gringo mine in andesite and the Helena mine in rhyolite, both gold mines, are examples.

## SUMMARY.

The metalliferous deposits occur in two great dissimilar groups. (1) Older deposits (Cretaceous) and (2) Younger deposits (Tertiary). About 54 per cent. of them appear to be genetically connected with intrusives later than the enclosing formation.

### OLDER DEPOSITS.

The older deposits are genetically connected with or occur in the Mesozoic acidic intrusive rocks, the granite, quartz monzonites, quartz diorite, granite porphyry, rhyolite porphyry, and aplites. Most of these contain as disseminated primary constituents pyrite and chalcopyrite carrying silver and gold. The genetic connection of the deposits with these rocks is also shown by the common occurrence of contact metamorphic deposits as in the Duquesne-Washington and Helvetia camps.

The presence of tourmaline, molybdenite, arsenopyrite, and other minerals commonly of deep-seated origin, and the strong metamorphism induced in the sedimentary host rocks, indicate that the deposits were probably formed at considerable depth, in the deep vein zone. With lowering of the surface by erosion, oxidation and descending meteoric waters have locally played an important rôle in concentrating the deposits, by processes of secondary enrichment, into workable ore bodies.

The most universal and widely distributed metal is copper. It is not only dominant in the contact metamorphic deposits and prominently associated with the lesser siliceous granitic rocks, the quartz diorite and the quartz monzonites, but it is also prominent in association with granite porphyry. The diorite seems to be the dominant silver-bearing formation while the granite leads in gold.

In the deposits in the sedimentary rocks which are chiefly contact-metamorphic deposits, the dominant metals are copper and silver, with molybdenum third in importance in some instances where the intrusive rock is granite, and zinc where the intrusive is the older quartz monzonite. Copper is also the dominant metal in vein and shear zone deposits genetically connected with lamprophyric intrusives in the early Paleozoic quartzite and schists. In replacement deposits in the limestone where genetically connected with intrusives the dominant metals are lead and silver, sometimes in a basic psilomelane-pyrolusite-hematite gangue.

The deposits in the acidic intrusive rocks occur mainly as quartz-barite veins and to a small extent as shear zone replacements.

In the deposits in granite, the dominant metals are gold, silver, and lead, but where the deposits are genetically connected with aplite or allied intrusives the order tends to be copper, lead, gold, silver, and molybdenite, and in some of the deposits molybdenite is the only metal.

In the deposits in the older quartz monzonite, which are mainly vein and shear zone deposits, copper is preëminently the dominant metal with lead second, and gold third. In 40 per cent. of the deposits including those genetically connected with granite porphyry, copper is the only metal present. In 30 per cent. lead ranks first, with silver or copper a strong second, and gold third, while in 10 per cent. of the deposits which are included in those which are genetically connected with the intrusive quartz diorite or allied rocks, the mines are worked for gold which is, however, associated with minerals of lead, silver, and copper, and with stibnite. In a few of the (vein) deposits genetically

connected with and partly contained in lamprophyric dikes, tungsten is the only metal.

In about 50 per cent. of the deposits occurring in the quartz diorite as in those of the older quartz monzonite, copper is the dominant metal, with silver commonly a close second, followed by lead and gold, with zinc, except as an associate metal, rare; in about 40 per cent. lead is the dominant metal with second place shared about equally by copper and silver; in about 10 per cent. silver is dominant; in a few iron is the only metal. Only 44 per cent. of the deposits appear to be in genetic connection with later intrusives in the quartz diorite; of these the most important is granite porphyry. In deposits connected with this rock the rank of the metals is not materially changed except that lead is moved to second place at the expense of silver, and in a few of the deposits gold ranks first. The quartz diorite beside containing about 30 per cent. of the deposits of the range, also as has been shown plays the rôle of later intrusive in genetic connection with 50 per cent. of the deposits occurring in the older quartz monzonite.

In the deposits in the granite porphyry which are chiefly vein and shear zone deposits, containing copper, lead, and silver, copper is the chief metal; in 60 per cent. of them it ranks first, in 25 per cent. lead is first, and in 15 per cent. silver is first, with copper second.

In the deposits in the younger quartz monzonite the dominant metal is copper, with gold and silver also present in some veins, and the rock itself like the older quartz monzonite in places contains primary minerals of copper.

### YOUNGER DEPOSITS.

The younger deposits occur chiefly in and are genetically connected with the Tertiary effusive volcanic rocks. They were formed relatively near the surface by ascending thermal solutions resulting from the magmas of the inclosing or associated rocks. They are regarded as of late Miocene or early Pliocene age. In these deposits, which occur chiefly as branching fissure veins

in andesite, rhyolite and quartz latite porphyry, an unusual feature is their generally base metal character and the tendency of the deposits to occur in two types, (1) tetrahedrite-rhodochrosite veins, and (2) quartz-galena-sphalerite veins. Copper is the dominant metal in the rhyolite areas some of which appear to contain pyrite and chalcopyrite. Some of the deposits, however, contain only gold and silver, and a few only gold.

# GEOLOGY AND ORE DEPOSITS OF THE TETIUXE DISTRICT, RUSSIA.

G. S. NISHIHARA.

## INTRODUCTION.

The Tetiuxe district is situated about 250 miles north of Vladivostock and 20 miles northwest of Tetiuxe Bay. A narrow gauge railroad connects with tidewater the ore-dressing plant

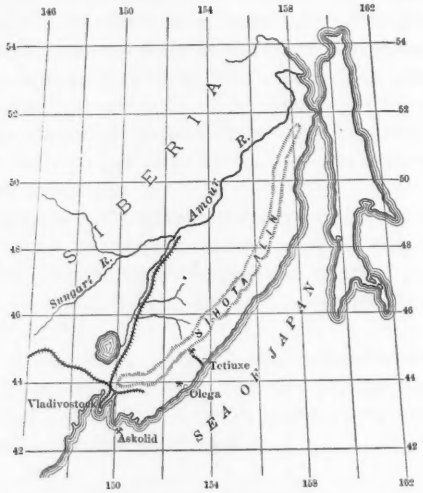


FIG. 5. Map showing position of Tetiuxe Mine, Siberian coast.

and mine of the Tetiuxe Mining Company, which is about 1,400 feet above the sea. The country is hilly, the highest peak reaching an elevation of about 3,500 feet. Mining is the principal industry of the region, although there is some logging, farming and fishing. The company employs about 2,000 men.

GEOLOGY.

The district is an area of limestone and quartzite intruded by diabase and quartz porphyry (Fig. 6). The limestone is generally light colored and non-crystalline, and near the ore body becomes

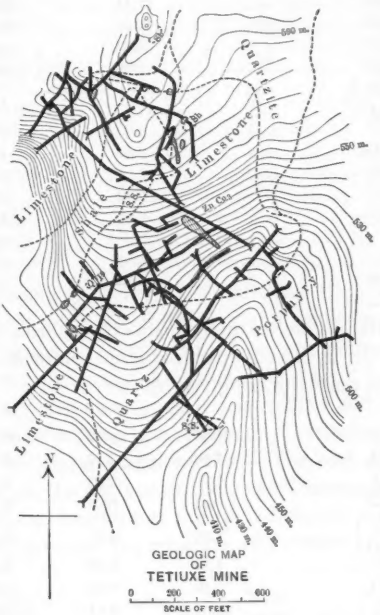


FIG. 6. Shaded areas are zinc carbonate.

darker. It contains coral impressions and is highly fissured. A chemical analysis of a sample taken near the ore body is as follows:

| | | | |
|---|---|---|---|
| $SiO_2$ | 1.15 | Cl | tr. |
| CaO | 54.16 | $CO_2$ | 43.32 |
| MgO | 0.60 | MnO | 0.00 |
| $Na_2O$ | tr. | $P_2O_5$ | 0.00 |
| $Fe_2O_3$ | 0.43 | | |

Inclusions of sandstone, cream white or dark gray, are found in the limestone. Chemical analyses of samples of the sandstone taken at the old surface working near the top of the hill are given below:

| | | |
|---|---|---|
| $SiO_2$ | 77.15 | 82.70 |
| $Al_2O_3$ | 10.95 | 10.64 |
| CaO | 0.93 | 0.32 |
| MgO | 0.98 | tr. |
| $K_2O$, $Na_2O$ | 1.41 | 1.44 |
| FeO | 3.00 | 1.29 |
| $Fe_2O_3$ | 0.40 | 1.29 |
| $P_2O_5$ | 0.12 | 0.09 |
| $H_2O$ | 0.42 | 0.33 |
| $H_2O-$ | 2.25 | 2.20 |
| Cl | tr. | 0.07 |
| $CO_2$ | 0.00 | 0.00 |
| MnO | 0.00 | tr. |

The quartzite is fine textured, distinctly bedded, and contains chert beds. It is closely folded and contorted. Chemical analyses of the quartzite are given below:

| | | | |
|---|---|---|---|
| $SiO_2$ | 90.96 | 95.20 | 96.60 |
| $Al_2O_3$ | 2.94 | 2.12 | 1.07 |
| CaO | tr. | 0.29 | 0.18 |
| MgO | 0.44 | tr. | tr. |
| $K_2O$, $Na_2O$ | 1.95 | 0.25 | 0.25 |
| FeO | 1.30 | 0.90 | 0.58 |
| $Fe_2O_3$ | 0.56 | 0.93 | 0.79 |
| $P_2O_5$ | 0.06 | 0.13 | 0.07 |
| $H_2O$ | 0.57 | 0.60 | 0.09 |
| $H_2O-$ | 1.10 | 0.22 | 0.52 |
| Cl | 0.07 | tr. | tr. |
| $CO_2$ | 0.00 | 0.00 | 0.00 |
| MnO | 0.00 | tr. | tr. |

The diabase is a medium-grained rock composed of pyroxenes and calcic feldspars. It is extensively exposed immediately south of the mine and has been regarded by some as closely connected with the ore deposit of the district. Its chemical analysis

(*a*) is given below. *b* is a dike rock which cuts the limestone on the lowest level of the mine.

| | (*a*) | (*b*) |
|---|---|---|
| $SiO_2$ | 60.75 | 47.75 |
| $Al_2O_3$ | 18.21 | 19.21 |
| CaO | 4.57 | 13.02 |
| MgO | 2.88 | 2.68 |
| $K_2O$, $Na_2O$ | 2.04 | 0.61 |
| FeO | 5.01 | 4.28 |
| $Fe_2O_3$ | 1.21 | 2.31 |
| $P_2O_5$ | 0.22 | 0.39 |
| $H_2O$ | 0.35 | 0.76 |
| $H_2O-$ | 2.44 | 3.12 |
| Cl | 0.09 | 0.07 |
| $CO_2$ | 2.06 | 6.28 |
| MnO | tr. | tr. |

Quartz porphyry is the most extensive rock in the district. Some portions of it are tuffaceous and others porphyritic, and in general it has a cryptocrystalline groundmass with white grains about 2 mm. in cross section. In color it is cream yellow, light blue, or light dirty pink. It is jointed and in some places shows flow structure, and frequently contains inclusions of masses of breccia and agglomerate. The rock weathers rather rapidly and on the surface of the ground assumes a spongy texture. Chemical analyses of the altered quartz porphyry exposed near the surface near the mine are as follows:

| | | |
|---|---|---|
| $SiO_2$ | 84.55 | 80.55 |
| $Al_2O_3$ | 8.04 | 11.10 |
| CaO | tr. | tr. |
| MgO | 0.62 | 0.18 |
| $K_2O$, $Na_2O$ | 2.64 | 2.61 |
| FeO | 0.65 | 1.54 |
| $Fe_2O_3$ | 0.50 | |
| $P_2O_5$ | 0.23 | tr. |
| $H_2O$ | 0.16 | 0.36 |
| $H_2O-$ | 0.50 | 2.30 |
| Cl | 0.06 | 0.07 |
| $CO_2$ | 0.00 | 0.00 |
| MnO | 0.00 | 0.00 |

ORE DEPOSITS.

The ore bodies are irregular deposits in limestone and are believed to have formed in connection with the intrusion of the limestone by quartz porphyry. The principal minerals of the primary ore are galena and zinc blende. They occur in the deeper zone with pyrrhotite and a little chalcopyrite. The chief gangue minerals are quartz, hedenbergite, and calcite. The

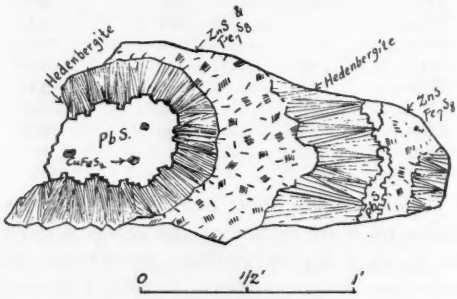


FIG. 7. Sketch showing general character of the sulphide ore.

hedenbergite occurs abundantly and intimately associated with the sulphides especially with the galena, some of which is enclosed within shells of hedenbergite. During the process of intrusion the limestone was brecciated and partly silicified along the zone of contact. During the period of the consolidation of the magma, iron, lead, zinc, and copper sulphides were deposited. The reducing action of the calcareous rocks probably aided the deposition of the primary sulphides. Partial silicification and brecciation of the limestone along the contact zone took place contemporaneously, followed by the replacement of the limestone by the primary sulphides. The contact breccia is cemented with the quartz and the iron sulphide at some places. This seems to indicate that the mineralization continued long after the consolidation of the magma along the contact zone. Usual contact minerals, such as garnet and epidote, are rare or absent in the

contact zone. This may indicate that the deposition took place at comparatively shallow depth. Hedenbergite, which occurs in long needles and radiated forms, is frequently associated with galena in the contact zone.

The deposits of chief commercial interest in the Tetiuxe mine are huge bodies of zinc carbonate ore which are found only in the limestone. Oxidizing waters acting on iron and zinc sulphides have dissolved the zinc and the solutions descending through joints and cracks in the limestone have reacted with calcium carbonate depositing zinc carbonate, the calcium going in solution.

The principal body of zinc carbonate ore dips south and southwest, following the slope of the hill. Its thickness varies, but

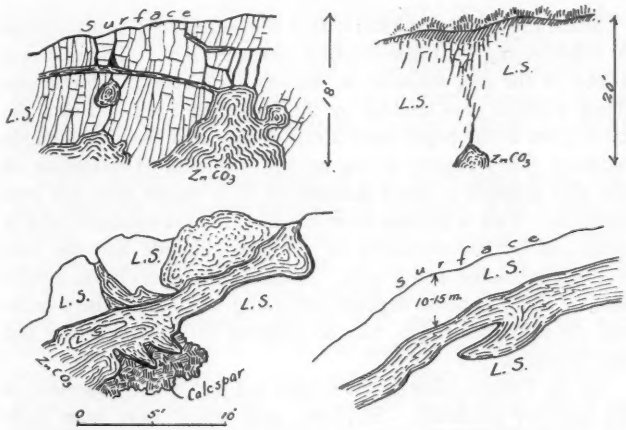


FIG. 8. Showing mode of occurrence of zinc carbonates in the limestone.

averages about five feet. At 540 m. elevation (see the mine map) where a great body of the galena and zinc blende is exposed only three feet from the surface, a zinc carbonate deposit was found on the top of the sulphides. This is shown in the sketch (Fig. 8). The analysis of the carbonate is as follows:

| | | | |
|---|---|---|---|
| Zn | 47.17 | $CO_2$ | 26.01 |
| Pb | tr. | $SiO_2$ | 0.70 |

Where the sulphide ore body is exposed on the surface the zinc blende is partly dissolved. As the result of the alteration of the sulphide ore body on the surface, a gossan is formed. Where galena had been abundant the gossan is light cream yellow in color, resembling powdered sulphur. The chemical analysis of the yellow gossan is as follows:

| | | | |
|---|---|---|---|
| $SiO_2$ | 42.51 | S | 2.05 |
| $Al_2O_3$ | 1.36 | Pb | 12.17 |
| CaO | 0.23 | Zn | 12.09 |
| MgO | 0.51 | Cu | 0.32 |
| $Fe_2O_3$ | 16.41 | MnO | 1.33 |
| $CO_2$ | 3.08 | | |

In the presence of sulphuric acid zinc sulphide is easily altered to sulphate and hydrogen sulphide gas is evolved. The reducing action of the zinc sulphide on the sulphuric acid and ferric sulphate solution was studied by the writer in 1914.[1] From the table given in the paper cited it can be seen that the zinc sulphide oxidized fairly rapidly in the acids. The rate of oxidation of the zinc sulphide is much accelerated if it occurs with the iron sulphide. This is obvious from the fact that the sulphuric acid is generated by the oxidation of the iron sulphide and the zinc sulphide is soluble in that acid. Notable differences in the alteration of zinc blende of deposits occurring with, and others without, the sulphide of iron, may be observed in Wisconsin zinc and lead deposits.

At the Tetiuxe mine pyrite is rare but pyrrhotite is present in the primary sulphides. Sulphuric acid would have been sufficient to have dissolved some of the primary zinc blende, which was undoubtedly the source of the zinc carbonate ore.

Sulphuric acid attacks the zinc blende and changes it to sulphate, evolving the hydrogen sulphide gas:

$$ZnS + H_2SO_4 = ZnSO_4 + H_2S.$$

[1] Nishihara, G. S., "The Rate of Reduction of Acidity of Descending Waters by Certain Ore and Gangue Minerals and its Bearing upon Secondary Sulphide Enrichment," ECON. GEOLOGY, Vol. 9, pp. 742–757, 1914.

When zinc sulphate comes in contact with the limestone carbonate of zinc is supposed to be formed:

$$ZnSO_4 + CaCO_3 + 2H_2O = ZnCO_3 + CaSO_4.2H_2O.$$

The process of the formation of zinc carbonate expressed in the above chemical equation is very simple, but many physical conditions that affect the chemical processes are little known.

In the spring of 1914, while carrying on some chemical experiments in the geological laboratory of the University of Minnesota, the writer made a few tests with the zinc sulphate solution. In about 300 c.c. of $N/10$ zinc sulphate solution a piece of calcite was placed. No change or action was observed in the beaker. The content was set aside for a period of three weeks, but still no change was observed. The zinc sulphate solution did not attack the calcium carbonate appreciably and no chemical change such as indicated in the accepted chemical equation seemed to have taken place. The writer's explanation was that the zinc sulphate being neutral or slightly alkaline could not attack the calcium carbonate.

When, however, a few drops of acid were added to the solution, vigorous action was started with evolution of $CO_2$ from the calcite. With sulphuric acid this vigorous action soon ceased and the calcite was covered with white coating. A few drops of methyl orange were added and the solution was found to be acid, showing that some sulphuric acid was still left in the solution. The calcite was taken out and the white coating was tested. It was found to contain only sulphate of calcium and no trace of carbonate of zinc. The end of the chemical action was therefore due to the formation of gypsum coating, which prevented the further action of the sulphuric acid upon the calcium carbonate.

Since the formation of the gypsum coating on the calcite prevented the further action of the acid, a pinch of sodium chloride was added to the solution. Then vigorous action was resumed and at the end of ten hours the calcite was honeycombed, losing

[2] Nishihara, G. S., *op. cit.*, pp. 745, 748, 749.

the original shape of the crystal. Probably the sodium chloride gave rise to the soluble calcium chloride. The action between calcite and sulphuric acid may proceed as follows:

$$2H_2O + H_2SO_4 + CaCO_3 = H_2CO_3 + CaSO_4.2H_2O.$$

And the precipitation of the zinc carbonate may take place thus:

$$H_2CO_3 + ZnSO_4 = H_2SO_4 + ZnCO_3.$$

In presence of sodium chloride:

$$CaCO_3 + 2NaCl + ZnSO_4 = CaCl_2 + Na_2SO_4 + ZnCO_3.$$

ANALYSES OF WATERS OF TETIUXE MINE—PARTS PER MILLION.

| | (*a*) | (*b*) |
|---|---|---|
| Total solid | 329.00 | 401.00 |
| $SiO_2$ | 50.00 | 10.00 |
| $Al_2O_3$ | tr. | tr. |
| CaO | 21.93 | 35.04 |
| MgO | 12.68 | 13.60 |
| $K_2O$, $Na_2O$ | 47.29 | 37.92 |
| FeO | tr. | tr. |
| $Fe_2O_3$ | 17.50 | 10.00 |
| Cl | 35.46 | tr. |
| $CO_2$ | 45.22 | tr. |
| $SO_3$ | 10.26 | 206.34 |
| Pb | tr. | tr. |
| Zn | 14.06 | 14.06 |
| Cu | tr. | tr. |

(*a*) was taken in the zinc carbonate ore body in the limestone.
(*b*) was taken at the lowest level in the quartz porphyry.

While the writer is not in a position to give a satisfactory explanation of the changes involved in the alteration of the Tetiuxe ores from the chemical standpoint, his observation of the deposit and the microscopic examination seem to indicate that the zinc carbonate was formed by the direct interaction between the zinc sulphate solution and the calcium carbonate of the limestone. Gypsum thus formed must have been carried away in solution, for it is usually not found with the zinc carbonate.

Any zinc in the zinc sulphate solution that was not reduced by the calcium carbonate should find its way farther down below, where it might be redeposited as some zinc mineral other than the carbonate, but no secondary zinc sulphide has been found in depth.

### ORE RESERVE.

The nature of the ore body is such that the tonnage ore cannot be readily estimated. The cubic content of the old workings, the change in the character of the ore minerals in depth, and the geologic relation of the ore bodies with the enclosing rocks were considered in a rough calculation from which it is estimated than there is about 300,000 tons of sulphides with 20 per cent. PbS, and 10 per cent. ZnS, and 10,000 tons of zinc carbonate containing 38 per cent. Zn.

# DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

## *A STUDY OF SOME HEATING TESTS.*

*Sir:*—In reply to Mr. Robert B. Sosman's discussion of the results as stated in my article on some heating tests on granite in ECONOMIC GEOLOGY, Vol. 10, pp. 348–367, 1915, I should like to state that I am glad Mr. Sosman has called attention to the effect of the inversion of quartz at 575°. As stated in the article on page 366 it was thought at the beginning of the work that this change should be effective, and had I been familiar with the contents of the article by Day, Sosman, and Hostetter[1] I would have recognized that it was one of the important factors. I am very glad to acknowledge this correction of my conclusion and Mr. Sosman's addition to the result, that "the essential cause of the shattering of granite by heat is therefore divisible into two parts: (1) the wedging and straining effect due to the fact that the minerals, originally in close contact, possess different coefficients of thermal expansion; (2) the similar effect produced by the rapid volume increase of quartz as its 575° inversion point is approached, and by the final sudden increase in volume at 575°."

I should like to add that my work was done to furnish evidence on one side or the other as to the effect of the inclusions in the quartz, and the results showed that their effect, as far as disaggregation is concerned, is negative.

W. A. TARR.

[1] "The Determination of Mineral and Rock Densities at High Temperatures," *Am. Jour. Sci.*, 37, 1–39, 1914.

## THE NEED OF ACCURATE ROCK CLASSIFICATION IN ENGINEERING CONTRACTS.

*Sir*:—The need of an accurate classification of the rocks involved in proposed engineering work is not always appreciated by the engineers and contractors in charge. To illustrate this point, the following striking incident is cited.

A short time ago one of the largest railroad companies of the West became involved in a lawsuit brought against it by a former contractor who had graded several miles of roadbed for the company. The grading was all done in shale and sandstone which was covered in places by decomposed rock material from the underlying terrain. The rock classification used in his contract was as follows:

1. Loose Rock—material which can be removed with a pick and shovel.

2. Soft Rock—material which can be removed by plow and scraper without blasting.

3. Hard Rock—material which requires blasting to remove.

Probably the above classification, or a similar one, has been used successfully by some engineers and it might often seem to be all that was necessary. In this instance, however, the trouble arose over the amount of material included under the second and third classifications. The contractor, claiming more yardage under no. 3 than the company would allow, sued for $12,500.

The company called in the writer and another geologist to make an examination of the ground in dispute. They found that the material encountered in the grading consisted of tufaceous sandstone, shale and weathered rock matter. This information could have been secured before the contract was let and an exact classification of the rock made, together with the price per cubic yard for excavating each class of material.

There are doubtless many similar instances where the initial precaution of engaging a geologist to make an examination and classify the rocks to be encountered in the proposed work would have meant a saving to the company concerned.

GRAHAM JOHN MITCHELL.

## ALUMINIUM HYDRATES.

*Sir*:—ECONOMIC GEOLOGY, Vol. XI., No. 7, contains a criticism, by Mr. L. L. Fermor, of my article entitled: "Aluminum Hydrates in the Arkansas Bauxite Deposits," that appeared in Vol. XI., No. 1, of your journal.

(In replying, I wish to offer due apologies for the rough condition in which my article appeared, a fact which was due in part to my own faults in arrangement.)

To answer all of Mr. Fermor's criticisms in detail would consume more time than I care to give the subject at present. To say the least, his discussion is very interesting and to some degree helpful, but because of its theoretic nature I can not see that any particular light has been thrown on the situation.

Some of the chief criticisms, together with my replies, are as follows:

1. Mr. Fermor claims that my results were vitiated to some degree because alumina was determined by difference instead of by direct weighing; so that such compounds as oxides of calcium, magnesium, chromium and others would serve to increase the amount of $Al_2O_3$ reported. I beg to state that such compounds are exceedingly rare if present at all and furthermore enough determinations of alumina by direct weighing have been made to establish a very satisfactory check between this method and the one generally employed.

2. Mr. Fermor seems to doubt my assertion that the $TiO_2$ is probably present in the bauxite as ilmenite. I too doubt that all of it is present as in this mineral, but I am positive that no appreciable amount exists as a colloidal hydrate as he suggests might be the case, for I have picked out and analyzed enough of the individual titanium bearing minerals to be satisfied that, on the whole, they approach ilmenite in chemical composition. Some strongly resemble ilmenite in physical characteristics, while others appear to be a straight form of $TiO_2$.

3. In his criticism of my use of the term kaolinite, Mr. Fermor probably has good grounds. We are told that the word kaolin

is a corruption of the Chinese Kao-ling, meaning high ridge, which was the name of a hill near Jauchau Fu from which the first samples of clay were sent to Europe early in the eighteenth century. In this country as least, the term kaolin is almost universally applied to those white burning clays which approach the formula of kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) while the latter term, as Mr. Fermor has pointed out, should properly be applied to the crystallized varieties of this formula. Though I am ignorant of how much of the clays associated with the Arkansas bauxite is of crystalline type, I am opposed, under any circumstances, to call these materials lithomarge. So long as we speak of the "Kaolinization of feldspars" I think it would be absurd for us to try to institute lithomarge as a general term for the resulting amorphous clay.

4. In regard to my secondary gibbsite, described on page 49, Mr. Fermor suggests that it might be just as reasonable to assume higher hydrates for the iron oxide and aluminum silicate instead of supposing a possible higher aluminum hydrate. He also suggests that hydroscopic water and an error in the determination of aluminum might affect my deduction. I spent some time in an endeavor to eliminate hydroscopic water, and I feel reasonably asured that only the smallest trace could have existed. Furthermore I took care to precipitate my alumina, obtaining slightly higher results than by the difference method. Say, therefore, that our gibbsite constitutes 95 per cent. of the sample instead of 94.60 per cent. as reported. This will leave 5 per cent. to be divided between hydrous minerals resulting from only 0.56 per cent. $SiO_2$ and 1 per cent. $Fe_2O_3$. Considering this beyond logical reason, I suggested, and still suggest, the possibility of a higher aluminum hydrate than the triple.

5. One of the chief comments on my paper, and one which I expected would be forthcoming sooner or later, related to my assumption of the existence of mineralogical bauxite or the dihydrate ($Al_2O_3 \cdot 2H_2O$). Mr. Fermor also attacked my usage of the terms gibbsite and diaspore, he assuming that these should be applied to the crystalline forms only. He very properly said

that this is touching upon a large subject and I must say that it is entirely too broad for the present discussion. Personally, I am in favor of extending the definitions of gibbsite and diaspore to include the amorphous forms rather than adopting alumogel or the *k* prefixes. I am particularly opposed to the latter system of nomenclature as I understand it to be used, for to be consistent with this we would have to apply the *k* to amorphous forms of all minerals which have crystalline representatives, and such practice would rob us of a great deal of significance, especially in those cases when there are several amorphous varieties of the same mineral composition.

If the amorphous hydrates of alumina were known only in the Arkansas field, then I might be in favor of distinguishing them from the usual types by some significant terms comparable with Alaskite, Nelsonite or Arkansite. The fact that Prof. Lacroix has adopted the term alumogel for amorphous varieties of aluminum hydrate is certainly a strong argument in favor of general application, but my personal objection to its usage is that it does not indicate whether the hydrate is of mono, di or tri hydrate type.

Now as regards my claim for the di-hydrate of aluminum, or bauxite, I note that Mr. Fermor points out as his chief criticism of my paper that I have "not produced any reason for believing in the presence in the Arkansas bauxites of a compound of the formula $Al_2O_3 \cdot 2H_2O$." I would ask that Mr. Fermor read again the paragraph at top of page 46. I admit that this is rather a suggestive reason which could be followed up with a great many theoretical pros and cons, and certainly I will be glad to receive from any one proof that bauxite does not exist. The fact that we have not recognized it is no proof. The existence of a number of elements was suspected before they were ever discovered, so from a purely theoretical point of view why is it not reasonable to grant the possibility, yes the probability, of $Al_2O_3 \cdot 2H_2O$ when we have established on the one side $Al_2O_3 \cdot 3H_2O$ and on the other $Al_2O_3 \cdot H_2O$?

Though the prime object of my article was not an attempt to prove the existence of bauxite as a distinct mineral, I do claim

that the data submitted give something more than mere theoretic evidence for its presence. Certainly I have no proof of any such compound, but I am in favor of leaving bauxite in the arena until we have absolute proof that it is or is not a product of nature.

In closing this hasty discussion I wish to say that I have always felt that we must look across the water to such men as my able critic, Professor Lacroix and others for our best and most up-to-date information on the subject of aluminum hydrates in general. However, I feel it my duty to object seriously to calling the clays associated with the Arkansas bauxites, lithomarge. Kaolinite, or better kaolin, is to our American bauxite fields as lithomarge is to the Indian laterite regions. For my part also I am in favor of the technical application of the terms gibbsite and diaspore to our aluminum hydrates regardless of whether they are crystalline. I have hopes that in the not distant future we will know that bauxite is a mineral.

D. C. Wysoe.

# REVIEWS

**Economic Geology.** By HEINRICH RIES, A.M., Ph.D. Fourth Edition, rewritten. xx + 856 pages, 291 figures, 75 plates. (John Wiley & Sons. Price $4.00.)

The fourth edition of the well-known text-book of economic geology by Professor Heinrich Ries recently made its appearance. It is larger and more profusely illustrated than previous editions and a greater number of mining districts are described. The previous style and arrangement is retained by the author. The book is divided into two parts, Part I., "Nonmetallics," and Part II., "Ore Deposits."

The number of pages devoted to Part I. is 425, and to Part II., 398. This, together with the precedence given to the nonmetallics, is presumably due to the author's greater familiarity with this class of deposits and to his evident opinion that they are the more important from both commercial and scientific standpoints.

Part I. is an exhaustive treatment of nonmetallics. The subject matter is brought up to date and particular emphasis is laid on the industrial aspects such as prices, uses, and the geologic features that make the materials commercially valuable. The last chapter of Part I. deals with underground waters. This subject is well presented, but it may be questioned whether its importance does not justify a somewhat more extended treatment.

Part II., devoted to ore deposits, has been thoroughly revised and enlarged. The treatment of the principles of ore deposits and the descriptions of mining districts have been brought up to date, and of especial interest are the newly added pages dealing with the extensive disseminated copper ores, colloquially known as the "porphyry coppers."

The first chapter of 67 pages is devoted to a general treatment of the principles of ore deposits, and it is evident that the author has devoted much time and study to its amplification and improvement. Lindgren's classification of ore deposits according to the temperature and pressure of ore deposition is added, along with Weed's.

An extensive bibliography of ore deposits of a general nature, divided according to subjects, follows.

The remaining chapters deal with the individual metals, starting with iron, followed by copper, lead and zinc, silver-lead, gold and silver, and

ending with the minor metals. The deposits of these metals are subdivided under origin, processes, and form; the individual districts are described under these subdivisions. Average workable yields of the different metals are given so that a student may understand what constitutes an ore of the respective metals.

This volume by Professor Ries is well introduced by the previous editions. As it is the only book on economic geology that covers the entire field of both nonmetallic and metallic deposits with descriptive matter and theory pertaining to each, it is bound to be widely used. It will be of great value to teacher and student alike and even where not adopted as a text-book it will certainly find extensive use as a reference volume. The large number of Canadian occurrences that have been added will give it a greater sphere of usefulness in Canada, and it can be advantageously adopted as a text-book in the Canadian colleges. Although it is now essentially a text-book of Economic Geology of United States and Canada brief mention of the more important foreign occurrences are contained in fine print in the body of the text.

The illustrations are carefully chosen and in sufficient abundance to allow the text to be readily grasped. They have been well produced and, with the exception of two or three such as Fig. 76, page 224, have been carefully prepared for reproduction. Wax cuts and half tones have been freely used. Abundant maps have been prepared to show at a glance the geographic distribution of each ore or mineral treated and the location of industries dependent upon them, such as cement plants. Additional value is given to the book by the complete statistical tables accompanying the treatment of each substance. While considerable space is given to them it is justified by the light they throw on the relative importance of the minerals and the geographic importance of industries dependent upon these minerals.

The complete and up to date bibliographies at the end of each chapter, classified as they are according to origin, occurrence, areal reports, etc., enable an investigator to turn immediately to the original references which deal with the diversified subjects and localities. Their extensiveness indicates the author's widespread consultation of the literature. The bibliographies, in contrast with those of the earlier editions, have been found to be accurate. This feature alone renders the book valuable and the reviewer here expresses acknowledgments to the author for the use he and others will make of them.

With the exception of topics such as clays, building stones, coal, and some others with which the author shows an extensive personal acquaintance, the book is essentially a compilation. It is however a compilation of far reaching nature as shown by the exhaustive bibliography and the

numerous illustrations from widely scattered sources. The author's personal experience of many occurrences indicated by his own photographs from numerous localities fills in details ordinarily lacking in most compilations and the part dealing with clays is a contribution. The whole volume indicates an immense amount of labor and painstaking care in assembling it on the part of the author.

In Part I Prof. Ries has given to students of economic geology the most able and comprehensive presentation of nonmetallics that has yet appeared, and it will serve as the standard text and reference on that subject. It indicates discriminating compilation with considerable contribution, though not to be considered a treatise of nonmetallics. The material is logically arranged and well presented. The writing is clear and concise.

In its present stage of incomplete development economic geology is an extremely difficult subject to present and there is so much room for difference of opinion as to the manner in which this may best be done that one may well hesitate to criticize so painstaking a piece of work. A few points however seem to the reviewer to merit discussion.

In a text-book of this nature where the volume is divided into two distinct parts, a few general paragraphs would be of value to serve as an introduction and a connecting link between the two and to point out their differences and relative importance. These differences are seldom appreciated by those who use the book most. The author implies this, not by any statements, but by the number of pages devoted to each part.

An unusual feature of the book is that more space is devoted to nonmetallics than to ore deposits. This distribution may in part be justified by the relative commercial importance of the two, but the greater complexity of ore deposits entitles them to more space. While nonmetallics represent a group of more or less unrelated substances and their treatment involves no serious complexities, every teacher of economic geology appreciates the complexities of ore deposits, and the difficulties attending a brief presentation of them.

Improvement might be made in arranging more clearly the headings and respective subdivisions. For example on page 550 "Production of Iron Ores" a small type, inset heading is under "Pyrite" a large type, center heading and the context shows the "Production of Iron Ores" has nothing to do with pyrite as would be indicated by the heading. On page 430 "Magnetic Segregations" is given the same sized type and position as "Syngenetic Deposits" of which the former is presumably a subdivision. Such arrangements confuse the reader.

Scattered among a host of excellent illustrations a number were

observed which are not pointed and have not been led up to in the text. They undoubtedly are significant in the articles from which they are drawn, but the transplanting of the illustrations, where the text which accompanied them had to be left out, makes them somewhat barren.

In Part II. the author is beset with the difficulty that confronts every teacher of economic geology as to how the subject shall be presented, whether by a study of processes or by metals involving a large amount of descriptive material. While the reviewer prefers the former, he appreciates the value of the latter, but is of the opinion that in a text-book too much descriptive material cannot be digested by the student. In this volume a considerable proportion is given over to descriptions of individual mineral districts. Descriptive material is of unquestionable value, but the volume might serve a wider field as a text-book if more space were devoted to the theoretical side and the principles of economic geology.

The arrangement of Part II. treats the deposits of the individual metals under origin, processes, and form. In this subdivision Lindgren's genetic classification is in part adopted. It is unfortunate in following the mode of treatment as given that camps like Ely, Bingham, Bisbee and Morenci are listed under contact metamorphic copper deposits when but a small proportion of the copper ore mined from these districts is of contact metamorphic origin. In the same way the famous Bonanza mine at Kennecott, Alaska, is listed under "Deposits of Intermediate Vein Zone, formed by Ascending Waters," thereby assigning to it a decisive place in a genetic classification when the origin of that deposit is by no means a settled question. The rich silver camp at Cobalt, Ont., is not described under silver ores but is listed under cobalt ores. The value of the cobalt produced is almost negligible as compared with the silver, yet from the descriptions and the places to which it is assigned a reader unfamiliar with the camp would infer that cobalt is the important metal and not silver. Also in the descriptions of Cobalt, Ont., it is stated (page 801) "The important ores are native silver, smaltite and cobaltite, but associated with them in varying quantities are niccolite, millerite, argentite, dyscrasite, pyrargyrite, arsenopyrite." Arsenopyrite, etc., are clearly not ores, and may or may not be even ore-minerals. Such statements may be confusing to students who would use the book as a text.

A few confusing and contradictory statements appear, as for example, on page 416, it is stated that the depth of the water table "in arid regions may be 100 feet or more" and on page 437 "in arid regions it may lie deep, sometimes 2,000 feet or more."

While the arrangement of Part II. leaves something to be desired, the

reviewer finishes his task with the feeling that Prof. Ries has enriched the literature of economic geology with a valuable book that will find a deserved place as a text-book in many schools of the United States and Canada and will be within reach on the reference shelf of all who are interested in economic geology.

ALAN M. BATEMAN.

**Principles of Oil and Gas Production.** By ROSWELL H. JOHNSON and L. G. HUNTLEY. New York, John Wiley and Sons, Inc., 1916. Pp. xv + 371 with 135 figs. Cloth 6 × 9.

This book has been reviewed by A. E. Fath in this journal.[1] Most of the unfavorable criticisms are of minor points, typographical errors, small features concerning references, etc., which are merely matters of professional editing. Other criticisms concern major features and are unjust. They do not give a true idea of the book.

The greatest value of the book lies in the fact that it is the first attempt to bring together the important American information about the production of oil and gas, and to publish it after critical study. There is no other book which even attempts to do this.

The references are abundant. So far as the writer has observed, they are accurate. Dates are lacking in many references, but for ordinary purpose the volume reference is enough. It is the only book published which contains references to the principal literature on oil, classified according to subjects, a fact which makes it indispensable to students. One will have no difficulty in finding the original sources in any good library, by using the references given.

The title is not misleading to those familiar with the oil industry. Oil men divide the industry into production, transport, refining and sale. The first division of the industry is treated in this work. It includes geology, valuation, drilling, operation of wells, etc. In its technical use "production" means much more than tables of figures. No other word could have been selected for the title of a book that covers the producing part of the business.

The writers are not very conservative in their use of theory. They treat many questions from an original point of view, stimulative to thought, and inspiring to students. Oil theories to-day are multitudinous and lacking in harmony. Geologists agree in a general way on the question of the organic origin of oil and of the practical truth of the anticlinal distribution of oil in wet sands. On most other points any oil geologist will disagree radically with the theories proposed by any other geologist. At the same time, if his mind is of generous calibre, he will

[1] ECON. GEOL., Vol. XI., pp. 764-7, December, 1916.

welcome the statement of new theories. To such men the wide variety of theory in this book is welcome. The true scientist will enjoy trying to demolish what he considers bad theory, and to strengthen what he considers good, but he will not condemn any general book on a new science, because it must of necessity include ideas which are not yet generally accepted. We do not know to-day what ideas we must abandon to-morrow, and what retain.

It is exceedingly difficult for the professional geologist to find the time required for a close scientific study of theoretical problems. That Johnson and Huntley have managed, in the midst of their professional activity, to produce an exhaustive general study of oil production, is a marvel to all, and a cause for thanks.

The minor shortcomings, which result from the pressure under which the authors work, seem like mountains to Mr. Fath, but most oil geologists are glad to overlook them, because of the general excellence of the work and its constant usefulness upon our desks.

The extended application of the diagrammatic method of presentation is commendable. The graphs showing the variation in percentage of naptha, and in gravity, are much more useful than the usual loose talk about "asphalt-base" and "paraffin-base" oils.

Important new points brought out for discussion are: (1) the consideration of the history of an oil reservoir (italics on p. 24); (2) the relation of the age of the formation to the character of its oil (p. 30); (3) the effect of irregular lenses on distribution of oils (p. 41, fig. 26); (4) the effect upon migration produced by the deposition of interstitial cement (p. 46) and by change in depth during deposition and erosion (p. 46) and during periods of regional oscillation (p. 47); (5) the probability that gravitational sorting of oil and water cannot take place except when the liquids are being moved by some other cause; (6) the presentation, in fig. 29, p. 50, of oil reservoirs in approximately true scale; (7) the full treatment of the irregularities of reservoirs and of the causes thereof (pp. 40–62); (8) the influence of localized cementation; (9) the possible influence of ancient sand-bars and sand-hooks in determining the location of oil pools (p. 60). (10) The shape of sand-bodies is discussed fully for the first time in an oil paper (pp. 61–62). (11) The description in chapter IX. of the effects of stratigraphic attitude upon oil accumulation is unusually full, and is clearly illustrated in new and original diagrams (figs. 33 to 39). (12) The attention called (p. 74) to the occasional occurrence of oil on simple "homoclines," or structures consisting of dip in only one direction, is a fact frequently overlooked by geologists. (13) That the distribution of oil, gas and water in a sand folded before gravitational assortment would be differ-

ent from the distribution in a sand in which there was gravitational assortment before the folding, is brought out for the first time (fig. 39). (14) The treatment of the deviation of the trend of many pools from the strike (p. 82, and figs. 41, 42) is original and very pertinent to studies in Pennsylvania and West Virginia. (15) There is a new graphic treatment (fig. 50) of the effect of offset wells.

The treatment of the subjects of leasing and of purchasing oil and gas rights (pp. 95 to 113) is an excellent guide in the acquirement of oil rights to fit various conditions. The chapter on the valuation of oil properties describes fully the main principles on which valuation should be based. The senior author's experience in valuation should enable him to give us a more specific treatment of the subject more easily applicable to actual concrete cases.

The long chapter (pp. 238 to 345) on the oil and gas fields of North America omits no field of consequence. It summarizes the geological conditions in nearly all of them, and gives adequate references, which connot be found conveniently in any other book.

Anyone who finds this a "disappointing book" can be satisfied only with his own ideal. Let him write a better book, if he can, especially if he be protected in a governmental or collegiate position, with most of his evenings and many daylight hours free to devote to the task. It will be welcome. For my part, I welcome with sincere thanks to the authors the appearance of their book on: "The Principles of Oil and Gas Production."

C. W. WASHBURNE.

**California Mineral Production for 1915.** By WALTER W. BRADLEY. California State Mining Bureau, Bulletin No. 71, August, 1916. Pp. 193.

It is the purpose of this review to present some of the facts of general interest pertaining to recent mineral production in California as the circulation of the bulletin is limited outside of the state. Mr. Bradley has compiled the statistics from direct returns from producers.

A chapter is devoted to each of the following economic products: fuels, metals, structural materials and industrial materials, followed by a chapter on the mineral production by counties. An appendix is added which contains the state and federal mining laws and a list of the bulletins of the State Mining Bureau to date.

The statistics pertaining to mineral production reveal the following facts. Total production for the year 1915 amounted to $96,663,369 worth of crude products. Forty-nine different mineral products are represented in the total and all but two of the fifty-eight counties con-

tributed. The state produces a greater number of mineral products than any other state, and their annual value is exceeded by that of only four other states, the great coal and iron-producing states of the east. It is the sole producer of borax, chrome and magnesite and leads in the production of gold, tungsten and platinum. In 1915 it was surpassed by Oklahoma only in the production of petroleum.

The forty-nine mineral substances produced in 1915 are antimony ore, asbestos, barytes, bituminous rock, borax, brick, cement, chromite, pottery clay, coal, copper, dolomite, feldspar, fuller's earth, gems, gold, gypsum, infusorial earth, iron ore, lead, lime, limestone, lithia, magnesite, manganese ore, marble, mineral paint, mineral water, natural gas, petroleum, platinum, potash, pumice, pyrite, quicksilver, salt, sandstone, silica, silver, slate, soapstone, soda, miscellaneous stone, tungsten and zinc. Of these, twenty-five products showed an increase in 1915 over the 1914 production and twenty showed a decrease. Four products, antimony ore, dolomite, lithia and slate, appear on the 1915 list which were not listed in 1914. The net increase was $3,348,596.

The California fuels, including coal, natural gas and petroleum, make up approximately 50 per cent. of the state's mineral wealth. Lignite coal of medium quality has been mined since 1860. In 1915 its production, chiefly from Amador, Contra Costa and Monterey counties, was valued at $26,662. Natural gas, valued at $1,706,480, was produced chiefly from Santa Barbara, Fresno, Kern, San Joaquin, Los Angeles and Orange counties. The production of petroleum amounted to 91,-146,620 barrels, valued at $43,503,837, from the following counties in order: Kern, Fresno, Orange, Santa Barbara, Los Angeles, Ventura and Santa Clara. There are 120 square miles of proven oil land in the state of which 69 per cent. is in Kern County.

The metal production for the year is valued at $34,577,214, of which gold is the most important, followed in order by copper, zinc, quicksilver, tungsten, silver, lead, manganese, antimony, platinum and iron. The gold, valued at $22,442,296, was produced from thirty of the fifty-eight counties, of which the most important in order are Amador, Nevada, Yuba, Sacramento, Butte, Calaveras, Tuolumne and Kern. The underground gold mines numbered 237. Of the placer mines, 96 are hydraulic, 58 are dredges, 61 are drift and 72 are surface or sluicing mines. The deep mines produced 61.64 per cent. of the 1915 yield. There was an increase of production of 8.66 per cent. in 1915 over that of the preceding year.

Copper, valued at $7,169,567, was produced from twenty-five counties, of which Shasta County was the biggest producer, followed in order by Calaveras, Placer and Plumas counties. The copper districts of the state may be classified as the Shasta County belt, the Coast Range de-

posits, the Sierra Nevada foothill belt, the eastern belt of Mono and Inyo counties and the southern belt of San Bernardino, Riverside and San Diego counties.

Zinc was produced in Shasta, Inyo and San Bernardino counties to the value of $1,617,383. This represents a remarkable increase over any previous production. The average price for the year was 14.2 cents per pound as compared with 5.1 cents in 1914.

Quicksilver has been produced since 1824 and it supplies at present about 80 per cent. of the nation's output. The value from twelve counties in 1915 was $1,157,449, with an average cost of $81.52 per flask as compared with a value in 1914 of $49.05.

Silver, valued at $851,129, was produced mainly from Shasta, Inyo, San Bernardino and Calaveras counties. This metal is produced as a by-product associated with copper, gold, lead and zinc ores.

Exploration for tungsten ores was greatly stimulated during the year, with the result that the known deposits of wulframite, hubnerite and scheelite were considerably increased. The total value for the year was $1,005,467.

Lead production from Inyo, Shasta, San Bernardino and Kern counties had a value of $225,426 with an increase in price per pound from 3.9 cents in 1914 to 4.7 cents in 1915.

Platinum is obtained in small amounts as a by-product of placer operations by gold dredges in Trinity and other counties. The value of the 1915 supply is estimated at $21,149.

Iron ore production is limited, as there is no economic supply of coking coal. Electric smelting or availability of petroleum fuel would lead to a vast increase in iron mining. Large deposits are known in Shasta, Madero and San Bernardino counties. The 1915 yield was valued at $2,584.

With reference to structural materials California is practically independent. Deposits of granite, marble, sandstone and slate are widespread throughout the state. A great variety of brick is produced annually, including common, fire, pressed, glazed and sand-lime brick. Cement is the most important of the structural materials, with a value in 1915 of $6,044,950. Cement plants are located in seven counties. The total value of the structural materials for the year was $13,459,047.

Classified under Industrial Materials are some products of lesser importance, whose production is dependent upon local markets. Most important are mineral waters, pyrite, limestone and pottery clay. The value of gems produced during the year was $3,565, a great contrast to the production in 1906 when a maximum value of $497,090 was attained. These gems include diamond, beryl, hyacinth, kunzite, green topaz, tour-

maline and beach stones. Two of the California gems, kunzite and benitoite, are found nowhere else in the world.

Of the first seven counties in point of production, all but two (Shasta and Amador) owe their position to their petroleum yield. Kern County, with a production valued at $25,335,184, or 26 per cent. of the state's total, holds first place without competition. Shasta County is second, due to copper, lead and zinc valued at $8,350,133. Nineteen counties have a production in excess of one million dollars.

M. G. EDWARDS.

# SCIENTIFIC NOTES AND NEWS[1]

PROFESSOR C. K. LEITH, of the University of Wisconsin, has recently completed a six weeks' course of lectures on "Metamorphic Geology" at the University of Chicago.

CHINA has recently instituted a geological survey under the direction of V. K. King, a graduate of the University of Glasgow.

AMONG the geologists carrying on work in South America at the present time are Waldemar Lindgren, E. S. Bastin and J. M. Boutwell.

R. A. F. PENROSE, JR., has just gotten out an interesting booklet on "What a Geologist can do in the War" for the Geological Committee of the National Research Council.

PROFESSOR J. F. KEMP is back at his desk and is gradually picking up his work once more.

J. D. IRVING has just returned from a short trip to the Cœur D'Alene district.

L. D. RICKETTS is recovering slowly and is able to get down to his office now and then.

A. M. BATEMAN is leaving for Alaska to carry on geological work for the Kennecott Copper Co.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

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